STATUS OF MINERAL RESOURCE INFORMATION FOR THE ROCKY BOY'S INDIAN RESERVATION, MONTANA

By

David A. Lindsey
U.S. Geological Survey

Michael Sokaski
George McIntyre
U.S. Bureau of Mines

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CONTENTS

SUMMARY AND CONCLUSIONS

The Rocky Boy's Indian Reservation has significant economic resources of gas, coal, and sand and gravel. Other identified resources that can be classed as subeconomic or those whose economic status is uncertain are uranium, niobium, vermiculite, nepheline syenite, and stone. There is also some potential for discovery of base and precious metals, rare earth minerals, and brick clay.

The Tiger Ridge gas field extends beneath the reservation, and this gas is presently the most important mineral resource. Additional extensions of the field are likely to be present and should be sough by drilling. Subbituminous coal of high quality is present in several beds within the Fort Union Formation; future development of the coal may be hindered by the limited extent and structural deformation of the coal beds. Coal in other formations is probably suitable only for local use. Abundant sand and gravel in the valley of Big Sandy Creek is available for local construction.

The most important subeconomic resource is probably the uranium associated with the Rocky Boy stock, at the head of Big Sandy Creek. The uranium occurs with niobium in the same mineral. The approximate size of the deposit has been estimated from drilling and assaying, but extensions of low-grade ore should be sought by drilling to determine the overall grade and tonnage with better accuracy. Vermiculite and iron sulfides also are present in the same locality. The iron-sulfide bearing rock should be assayed for base and precious metals. Some testing of nepheline syenite might be desirable.

INTRODUCTION

Purpose

This report was prepared for the U.S. Bureau of Indian Affairs by the U.S. Geological Survey and the U.S. Bureau of Mines under an agreement to compile and summarize available information on the geology, mineral and energy resources, and potential for economic development of certain Indian lands. Sources were published and unpublished reports as well as personal communications. There was no field work.

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Location and Access

The Rocky Boy's Indian Reservation covers the west end of the Bearpaw Mountains and the valley of Big Sandy Creek, about 20 miles southwest of Havre, Montana (Figure 1). The Burlington Northern Railroad and U.S. Route 87 pass through the villages of Big Sandy, Boxelder, and Laredo and connect the reservation with markets and services in Havre, Fort Benton, and Great Falls. A paved road connects U.S. 87 with the agency headquarters at Rocky Boy Agency. Gravel and dirt roads provide access to most of the reservation.

Land Status

The reservation consists of 107,615 acres (U.S. Dept. Commerce, 1974) held by the Chippewa-Cree tribe. The original reservation was created in April 1916, when Congress set aside 56,035 acres from the Ft. Assinniboine military reserve (U.S. Dept. Commerce, 1974). Substantial acreage was added by Congress in 1939. None of the land has been allotted, and both surface and mineral rights are owned by the tribe.

PHYSIOGRAPHY

The Rocky Boy's Indian Reservation lies within the Northern Great Plains physiographic province (Howard and Williams, 1972) and is divisible into three physiographic units: (1) the alluvial valley of Big Sandy Creek, (2) the upland plain, and (3) the Bearpaw Mountains.

The alluvial valley of Big Sandy Creek, called locally the Laredo Flats, is a broad, flat plain bounded by low bluffs of glacial deposits laid down during the ice ages. The valley was cut before the ice ages by the ancestral Missouri River, when that stream flowed north of the Bearpaw Mountains along the course of the present Big Sandy Creek and Milk River. The valley is filled with alluvium from the ancestral Missouri River and with glacial deposits that have been reworked by Big Sandy Creek.

The upland surface extends on both sides of Big Sandy Creek to the east and is broken by the foothills of the Bearpaw Mountains. It consists of an extensive cover of glacial deposits over sedimentary rocks. High alluvial terraces and pediments occur along stream valleys and on the flanks of the mountains. The plain has been extensively dissected by streams, and buttes and hills of resistant igneous rocks rise more than five hundred feet above the plain.

The Bearpaw Mountains are composed of resistant igneous rocks that were erupted from volcanos or intruded into sedimentary rocks during Eocene time, before the formation of the alluvial valley and the upland plain. The area was uplifted prior to volcanism, so that a highland has existed in the Bearpaw region for more than 50 million years. The Bearpaw volcanic pile has been dissected by streams to form the present range.

PREVIOUS INVESTIGATIONS

The geology of the Bearpaw Mountains region was first investigated by W. H. Weed and L. V. Pirsson in October 1895. They made sketches of local topographic and structural features and reported extensively on the igneous rocks of the region (Weed and Pirsson, 1896; Pirsson, 1905). Discovery of coal and lignite on both sides of the Milk River and around the northeast and west sides of the Bearpaw Mountains soon led to detailed mapping and study of these deposits by the U.S. Geological Survey (Pepperburg, 1910a, 1912;

Bowen, 1914a, 1914b). At the same time, a brief examination was made of metal deposits in prospects of the Bearpaws (Pepperburg, 1910b).

The second period of investigation by the U.S. Geological Survey was directed toward the location of stratigraphic and structural traps for oil and gas on the Montana plains. These studies spanned more than four decades (Collier and Cathcart, 1922; Reeves, 1924a, 1924b: Knechtel, 1944; Lindvall, 1953, 1956, 1961, 1962) and resulted in geologic and structure maps of the plains around the Bearpaw Mountains.

The most intensive geologic study of the area within the Rocky Boy's Reservation began in the late 1930's, when W. T. Pecora and associates at Harvard University and later at the U.S. Geological Survey began detailed mapping and study of the igneous rocks of the Bearpaw Mountains. Their work provided complete geologic maps of the Bearpaw Mountains, and four of these maps cover most of the reservation (Pecora and others, 1957a, 1957b; Kerr and others, 1957; Stewart and others, 1957). Aeromagnetic surveys of the same area were conducted also (Balsley and others, 1957a, 1957b, 1957c, 1957d). Numerous reports on the details of the local geology were published, including two detailed studies of the alkalic igneous rocks on Rocky Boy Mountain (Pecora, 1942, 1962).

As part of the Department of the Interior's program of studies to examine the mineral resources of the Missouri River Basin, the U.S. Bureau of Mines prepared a preliminary report on the mineral resources of the Rocky Boy's Reservation (Hubbard and others, 1963) and the Geological Survey prepared maps showing the general distribution of the mineral resources of Montana, including the reservation area (Larrabee and Shride, 1946; Chace, 1947). More recent compilations of resource data of Montana locate and discuss mineral resources on the reservation (Bentley and Mowat, 1967; U.S. Geological Survey, 1958).

Recent discoveries of large gas fields in northern Montana, such as the Tiger Ridge field along the north boundary of the reservation, have been followed by publication of detailed analyses of the structural and stratigraphic controls of gas occurrence (Maher, 1969; Sampsel, 1969; Martin, 1969) and on the production performance of individual fields (Bayliff, 1975). Exploration for gas is continuing (George and others, 1976).

GEOLOGY

General

The Rocky Boy's Indian Reservation is on the northeast structural slope of the Sweetgrass arch and the central Montana uplift, where Paleozoic and Mesozoic strata descend into the Williston Basin of eastern Montana, North Dakota, and Canada (Dobbin and Erdmann, 1955; Grose, 1972). This structural slope (Figure 2) is not uniform, but is interrupted by numerous uplifts caused by intrusion of igneous rocks in such ranges as the Sweetgrass Hills, Little Rocky Mountains, Moccasin and Judith Mountains. The Bearpaw arch extends toward the basin nearly at right angles to the slope of the regional structure, and the reservation is situated on the crest and northwest flank of the arch.

Sedimentary rocks of marine origin were deposited during part of Paleozoic and Mesozoic time. Near the end of the Mesozoic Era, uplift of the Rocky Mountains to the west shed sandy sediments eastward and sedimentation changed from marine to continental. Some of the Mesozoic formations are favorable host rocks for coal, oil, and gas deposits. The sea left Montana in early Cenozoic (Paleocene) time and streams deposited coarse conglomeratic sediments in early Eocene (Wasatch) time.

The Bearpaw arch (Figure 2) rose in middle Eocene time, causing large-scale sliding of Mesozoic strata down its flanks to form a vast area of thrust faults in the Montana plains (Reeves, 1924a, 1924b, 1925, 1946). These structures were instrumental in trapping deposits of oil and gas found near the reservation. Shortly after the rise of the Bearpaw arch, alkalic magmas intruded the arch and volcanic eruptions spread lava flows, breccias, and tuff over the arch to form the Bearpaw volcanic field (Figure 2) (Schmidt and others, 1964). Eruption of similar lavas formed the nearby Highwood Mountains at about the same time. Sliding was thought by Schmidt and others (1964) to have preceded volcanism, but Hearn (1974) believes that sliding followed volcanism and involved the volcanic rocks in the slides, pulling the Bearpaw volcanic field away from the crested area of the arch. Streams breached the Bearpaw volcanic field in mid-Tertiary and late Tertiary time, exposing stocks and plugs of igneous rocks, some of which probably represent the roots of the Bearpaw volcanos.

The geologic map (Figure 3) of the reservation and vicinity shows the distribution of the principal rock units and important structures, but its scale does not permit illustration of the geology in the same detail as the source maps. One should refer to the source maps to locate features easily in the field. The rock units exposed on the reservation are summarized in Table 1.

TABLE 1

Generalized Stratigraphic Section, Rocky Boy's Indian Reservation, Montana. Formal Stratigraphic Names Are Underlined

Map symbol on Figure 3	Age	Stratigraphic unit--Brief description	Thickness in feet
Qal	Quaternary: Holocene	Alluvium - gravel and silt in valleys	0-25+
Qg	Quaternary: Pleistocene	Glacial outwash - local deposits of well sorted sand and gravel; abundant poorly sorted, glaciofluvial deposits	0-150+
Qtp	Quaternary: Pleistocene	Terrace and pediment deposits - well-sorted gravel, sand, and silt in terrace gravel; poorly sorted coarse-grained sediment in pediment gravel	0-50+
	unconformity		
Tyv	Tertiary: Eocene	Younger volcanic rocks - flows of mafic phonolite are porphyritic trachyte. Some local intrusive rocks included.	2,000
	unconformity		
Ti	Tertiary:	Intrusive rocks - stocks, plugs, dikes and sills of porphyritic potassic syenite, monzonite, latite porphyry, syenite, shonkinite, and biotite pyroxenite	
Tov	Tertiary: Eocene	Older volcanic rocks - flows, breccias, tuffs and volcanic sediments of mafic and felsic volcanic rock. Some local intrusive rocks included. Felsic volcanic rocks contain inclusions of Precambrian basement rocks	5,000
	unconformity		
Ts	Tertiary: Eocene and Paleocene	Tertiary sedimentary rocks:	
		Eocene <u>Wasatch Formation</u> - siltstone, sandstone, mudstone, and claystone. Conglomerate lenses in upper part.	700
		Paleocene <u>Fort Union Formation</u> - sandstone, siltstone, shale, and minable coal beds	1,300
Km	Upper Cretaceous	<u>Montana Group</u>:	
		<u>Hell Creek Formation</u> - siltstone and claystone; ledge-forming sandstone in lower part	425
		<u>Fox Hills Sandstone</u> - sandstone, lower part forms ledges; partly marine	75
		<u>Bearpaw Shale</u> - marine shale, gypsiferous clay, and bentonite; contaills numerous septarian concretions and gypsum crystals	1,200

		Judith River Formation - sandstone, siltstone, gypsiferous claystone, lignite beds and carbonaceous shale; oyster-shell beds and minable lignite extensive in upper part	550-650
		Claggett Shale - marine shale, gypsiferous clay, bentonite, and abundant septarian concretions; multiple bentonite beds in basal part	500
		Eagle Sandstone - lower massive sandstone (Virgelle sandstone member) 80-100 ft thick; shale and thin coal beds in middle member, passing laterally into sandstone; sandstone in upper member; abundant natural gas locally in upper part	275
Kc	Lower and Upper Cretaceous	Colorado Shale:	
		Telegraph Creek Member equivalent - sandstone, mudstone, black shale, and lenses of limestone	200-300
		Niobrara and Carlile Shale equivalents - dark marine shale with limestone concretions and lesser sandstone, limestone, and bentonite beds	850
		Greenhorn Limestone equivalent - silty and sandy marine limestone, calcareous and noncalcareous shale; limestone more abundant in upper and lower parts	20-40
		Belle Fourche Shale equivalent - dark marine shale with lesser sandstone and bentonite beds	200
		Mowry Shale equivalent - shale with paper-thin laminations, siliceous shale, and fine-grained sandstone	50-100
		Newcastle and Skull Creek Shale equivalents - black shale, glauconitic sandstone, and lesser bentonite beds	200-250
		Fall River Sandstone equivalent - black shale, mudstone, sandstone, and chert pebble beds; phosphate nodules in shale near base	150-200
Kk	Lower Cretaceous	Kootenai Formation - sandstone siltstone, shale, and minor limestone; shale dominant in upper part and sandstone in lower part	275
	unconformity		
Je	Jurassic	Ellis Group - limestone, shale, and sandstone, locally metamorphosed	400-500
	unconformity		
Mm	Mississippian	Madison Group - limestone metamorphosed to white marble; about 150-200 feet exposed	

Sedimentary Rocks

Madison Group

Only the top 150-200 feet of the Madison Group is exposed on the reservation, along the south side of the Rocky Boy stock (Figure 3) (Pecora and others, 1957a). The limestone here has been metamorphosed to light gray to white marble, and is unlike Madison likely to be encountered in the subsurface. The uppermost 60 feet of the Madison is exposed also in the Suction Creek Dome to the east of the reservation, where gray massive limestone containing crinoids, corals, and chert is present (Hearn and others, 1964) . The total thickness of the Madison Group in the subsurface of the Bearpaw Mountains area ranges from 650 feet to 1,050 feet. The nearest well-exposed sections are in the Little Rocky Mountains (Figure 2), where the group has been divided into the Mission Canyon Limestone (upper) and the Lodgepole Limestone (lower) (Sando and Dutro, 1974). Paleozoic strata that formerly overly the Madison were eroded from the Bearpaw region during Jurassic time (Maughan and Roberts, 1967).

Ellis Group

Only about 300 feet of metamorphosed limestone, shale, and sandstone representing the Ellis Group is exposed along the southern edge of the Rocky Boy stock (Pecora and others, 1957a). Elsewhere in the Bearpaw region, the Ellis Group is exposed in the Suction Creek dome, where it is about 430 feet thick (Hearn and others, 1964). The Ellis here is divisible into three formations: the Middle Jurassic Piper (100 feet thick) and the Late Jurassic Rierdon (160 feet) and Swift (170 feet) formations. The Piper Formation is often referred to as the Sawtooth Formation in western Montana; the term "Piper" is applied east of the Sweetgrass Arch (Nordquist, 1955). It is the source of oil production in the Bowes field north of the Bearpaw Mountains.

The following description (from Hearn and others, 1964) applies to the Ellis Group in the southeastern Bearpaws. The base of the Ellis is marked by about four feet of conglomeratic sandstone and siltstone containing chert pebbles derived from the underlying Madison Group. This unit passes upward into about 65 feet of gray fossiliferous limestone and shale followed by about 30 feet of sandstone and sandy limestone beds at the top of the piper. The overlying Rierdon Formation consists mostly of gray calcareous shale and argillaceous limestone. The Swift Formation, from bottom to top, consists of shale, siltstone, and crossbedded sandstone with considerable interbedding of the three lithologies.

Kootenai Formation

The Kootenai Formation consists of about 275 feet of light gray sandstone, variegated siltstone and shale, and dark gray limestone beds (Pecora and others, 1957a). It is exposed only along the south side of the Rocky Boy stock. The lower 50 feet is massive crossbedded sandstone (Schmidt and others, 1964) that commonly displays a distinctive "salt and pepper" appearance owing to the presence of abundant dark chert grains; it is equivalent to the "third Cat Creek sand" of the subsurface (Hearn and others, 1964). The upper, variegated part of the Kootenai contains red, purple, green, and tan siltstone and shale with less sandstone than the lower part; the "second Cat Creek sand" in the Kootenai in other parts of Montana has not been identified in the Bearpaw region.

Colorado Shale

The Colorado Shale, 1,640-1,930 feet thick, consists mainly of dark gray shale and lesser amounts of other sedimentary rocks. It can be divided into several members that are correlative with named units in the Black Hills (Cobban, 1951). Elsewhere in Montana, sands in the Colorado Shale act as petroleum reservoir rocks. Three sandy horizons are present in the Colorado Shale of the Bearpaw region: 1) the upper part of the Fall River Sandstone (as mapped by Schmidt and others, 1964, and Hearn and others, 1964), is probably equivalent to the petroleum-bearing Muddy sandstone of southeastern Montana and is above the "first Cat Creek sand" of drillers in central Montana; 2) the glauconitic marine sand of the Newcastle Sandstone; and 3) sandstones in the Telegraph Creek Formation, near the top of the Colorado (Schmidt and others, 1964). The lowermost 30 feet of the Fall River Sandstone contains dark shale with phosphatic concretions (Pecora and others, 1962). Above the Newcastle Sandstone about 50100 feet of papery siliceous shale, siltstone, and siliceous sandstone represent the Mowry Shale. The lower-upper Cretaceous boundary has been placed near the top of the Mowry. The Mosby Sandstone member of central Montana is represented in the Bearpaw region by beds within or just below 20-40 feet of silty and sandy limestone and shale equivalent to the Greenhorn Limestone.

Montana Group

The Montana Group consists of six formations totaling slightly more than 3,000 feet thick in the Bearpaw region (Table 1). Three major sand horizons--the Eagle, Judith River, and Fox Hills-Hell Creek--were formed by deposition of beach and fluviatile sediments along the Late Cretaceous coast from volcanic highlands in western Montana (Gill and Cobban, 1973). These three sand sequences intertongue with and are separated by the Claggett and Bearpaw Shales in central and northern Montana. These dark shales represent major transgressions of the Late Cretaceous sea upon the highlands to the west. The shales contain numerous bentonite beds that formed by alteration of volcanic detritus erupted from the Elkhorn Mountains and other volcanic centers in western Montana.

The sandstones of the Montana Group are of considerable economic importance because two of them, the Eagle and Judith River, are important gas reservoirs near the reservation. To the southwest and west, these sandstones also contain fossil beach placers rich in magnetite and other heavy minerals (Houston and Murphy, 1970). The middle part of the Eagle and the upper part of the Judith

River Formation contain thin beds of coal (Lindvall, 1956).

The Eagle is generally divided into three members: the Virgelle Sandstone, the middle member (shale and sandstone), and an upper sandstone member (mainly sandstone with some conglomeratic lenses) (Rice, 1976). In the Big Sandy area, southwest of the reservation, the Virgelle member is 80-100 feet thick and the middle and upper members together are 125-150 feet thick (Lindvall, 1956). Some of the sandstones are excellent reservoir rocks for oil and gas.

Tertiary

The Cretaceous rocks of the Bearpaw region are overlain by continental sediments assigned to the Paleocene Fort Union and Eocene Wasatch Formation on the basis of plant fossils (Brown and Pecora, 1949). As much as 2,000 feet of these strata are exposed around the south and west sides of Centennial Peak (Stewart and others, 1957). Siltstone, sandy shale, carbonaceous shale, and thick beds of sandstone make up most of the Fort Union Formation. Minable beds of coal occur in the Fort Union at sec. 18, T. 28 N., R. 13 E., and in T. 29 N., Rs. 14 and 15 E. The Wasatch Formation is a variegated sequence of about 700 feet of sandstone and shale in the lower part and sandstone and conglomerate in the upper part (Brown and Pecora, 1949; Stewart and others, 1957).

Igneous Rocks

Older Volcanic Rocks

The older volcanic rocks lie unconformably on the Wasatch Formation and contain Eocene plant fossils in interbedded tuffaceous sediments (Brown and Pecora, 1949). The rocks have been divided (Pecora and others, 1957a, 1957b; Stewart and others, 1957; Kerr and others, 1957) into mafic and felsic volcanics, but the two units are interbedded and of the same general age. After deposition the volcanic rocks of the Bearpaws have been divided by gravity sliding and erosion into the northern and southern fields.

The mafic volcanics consist of dark flow rocks, breccias, and some beds of pyroclastics and tuffaceous sediments. Relative to other mafic volcanic rocks, they are low in silica and high in alkali oxides so that they are classed with the alkalic igneous series; they typically contain sanidine and augite, with or without leucite, analcime, plagioclase, olivine, and biotite. Alteration minerals include the zeolites, natrolite and analcime.

The felsic volcanic rocks consist of light-colored flows, breccias, mud flows, lenses of tuffaceous sediments, local intrusive rocks, and coarse vent agglomerate. Many of the felsic rocks are related to the alkalic and silicic-alkalic igneous series, and include latite, quartz latite, and trachyte. Inclusions of Precambrian basement rocks--pyroxenite, gabbro, anorthosite, granite, gneiss, and schist--are abundant.

Intrusive Rocks

Major bodies of intrusive rock are shown on the geologic map (Figure 3) as sills, laccoliths, plugs, and stocks; not shown, because of scale, are hundreds of small dikes, sills, and plugs. The published detailed geologic maps show location of these small plutons (Pecora, 1957a, l957b; Kerr and others, 1957; Stewart and others, 1957). The intrusive rocks belong to the alkalic and silicic-alkalic series, being composed principally of porphyritic potassic syenite, monzonite, porphyritic latite, syenite, shonkinite, and biotite pyroxenite. They cut the older volcanic rocks, whose chemical composition they resemble, but predate later volcanic rocks.

The Rocky Boy stock is the largest intrusive on the reservation (Figure 3). This is a composite stock containing, in order of intrusion, (1) biotite pyroxenite, (2) shonkinitic and syenitic rocks, (3) monzonite and quartz monzonite, (4) nepheline syenite and related dikes and pegmatites; (5) porphyritic potassic syenite and related dikes and carbonatites (silicatecarbonate-sulfide veins), and (6) dikes of mafic analcime phonolite (Pecora, 1942, 1962; Pecora and others, 1957a). It is perhaps the best exploration target for minerals other than hydrocarbons in the Bearpaw Mountains. The porphyritic potassic syenite at the head of Big Sandy Creek contains an area of disseminated sulfide minerals (SE¼NE¼ sec. 19, T. 28 N., R. 16 E.) and vermiculite prospects (Pecora and others, 1957a). Rare-earth carbonate minerals and uranium-rich pyrochlore have been identified in the carbonatite veins (Pecora and Kerr, 1953; Pecora, 1962).

A small stock Oil Beaver Creek (sec. 10, T. 28 N., R. 16 E.) contains shonkinite, syenite, and monzonite similar to the sequence in the Rocky Boy stock. A large stock of monzonite occurs at Number One Mountain, along the north edge of the reservation.

At Boxelder Butte (Squarre Butte) shonkinite and syenite form a layered laccolith (Pecora, 1941) which was formed by two injections of alkalic magma along bedding planes in the Judith River Formation. A similar, but poorly exposed, laccolith is on Duck Creek, about 5 miles south of the Boxelder laccolith.

Younger Igneous Rocks

These rocks consist of about 2,000 feet of mafic phonolite flows, trachyte flows, and agglomerate with some interbedded pyroclastic tuffs, all of which unconformably overlie the older igneous rocks (Pecora and others, 1957a). The sequence is best exposed on Mt. Bearpaw, east of the Rocky Boy stock. On Mt. Bearpaw and in the Long George Peak areas and Parker Peak to the north, trachyte flows underlie the phonolite flows. Extensive flows of mafic phonolite crop out on Centennial Mountain, also. Plant fossils from the younger volcanics indicate a probable middle Eocene age.

Surficial Deposits

Terrace and Pediment Deposits

Erosion of the Bearpaw Mountains region developed a pediment surface that was adjusted to the ancestral Missouri River, which at that time flowed to the northeast and east on the west and north sides of the Bearpaw region (Stewart and others, 1957; Pecora and others, 1957a). Remnants of this plain are visible as high as 4,600 feet and descend to the foothills, where the pediment surfaces coalesce in broad plains. The plains are recognizable by the abundance of coarse and angular cobbles on the surface; locally as much as 50 feet of poorly sorted gravels are present. In the lower regions the pediment surfaces give way to terraces of well-sorted sand, gravel, and silt along valley sides. At least three periods of pediment and terrace development are present; each represents adjustment of the drainage to some change in climate or elevation of the area.

Glacial Deposits

In Pleistocene time a continental ice sheet advanced southeast toward the Bearpaw Mountains, filling the valleys to a height of about 4,000 feet (Stewart and others, 1957). The ice sheet left a cover of glacial till (poorly sorted clay, sand, and boulders) that is generally only a few feet thick but may exceed 100 feet in preglacial valleys. This cover of glacial debris is not shown on the geologic map (Figure 3).

As the ice sheet melted and retreated, large deposits of glacial out- wash (well-sorted sand and gravel) were deposited by streams issuing from the glacier. These deposits are abundant in the vicinity of Boxelder (Figure 3).

Alluvium

The valley floors of the present streams contain silt, sand, and gravel. These deposits have been reworked from glacial and preglacial deposits and locally they may be a source of sand and gravel.

Structure

The dominant structural features of the reservation area are the high-angle faults associated with the Bearpaw arch. East-northeasterly trending faults and dike swarms are alined parallel to the axis of the arch; a set of northwesterly-trending faults cross the area (Figure 3). These faults probably developed during gravity sliding of sedimentary and volcanic strata away from the Bearpaw arch in Eocene time and do not extend below the Greenhorn Limestone in the Colorado Shale (Reeves, 1946; Maher, 1969; Hearn, 1974). The strata below the Greenhorn are much less deformed and are believed to dip smoothly away from the Bearpaw arch at slopes of 30 to 200 feet per mile (Hearn, 1974). The fault blocks were instrumental in trapping large quantities of natural gas in the Bearpaw region. Intrusion of the Rocky Boy stock tilted adjacent strata up, and they dip away from the center of the stock.

GEOPHYSICAL FEATURES

An aeromagnetic survey of much of the reservation and the adjoining area of the Bearpaw Mountains was flown in 1950 (Balsley, 1957a, 1957b, 1957c, 1957d). North-south flight lines were spaced approximately one- half mile apart and 1,000 feet above the surface. Results for the reservation and vicinity are shown on Figure 4.

Areas of high magnetic intensity generally correspond to strongly magnetic volcanic rocks that do not extend to great depths or correspond to the distribution of igneous rocks that may extend to considerable depth. Thus the Rocky Boy stock and plutons to the northeast show large positive magnetic anomalies, as do the volcanic rocks on Centennial Mountain and the plutons and volcanic rocks to the northeast. These magnetic features define an east-northeasterly structural grain that runs parallel to both sides of the axis of the Bearpaw arch. The area underlain by Cretaceous sedimentary rocks exposed along the axis is a magnetic low, and does not appear to contain shallow buried intrusives. The lack of large magnetic anomalies west of the mountains suggest that no large body of intrusive rock underlies the plains.

Several areas of low magnetic intensity may result from hydrothermal alteration of magnetic minerals. Other characteristics, such as the shape, depth, remanent magnetism, and magnetic susceptibility of rock units can also cause magnetic anomalies (Books, 1962). A low magnetic anomaly in the east central part of the Rocky Boy stock (sec. 19, T. 28 N., R. 15 E.) coincides with an area of vermiculite occurrence and other known alteration. The elongate low anomalies east and north of Rocky Boy Agency (T. 29 N., R. 15 E.) may be due in part to reversely magnetized volcanic rocks, but the lows also coincide with the trend of faults in volcanic rocks that might have been altered. A series of magnetic low anomalies rings the northern side of the monzonite stock of Number One Mountain, also. Field examination would be required to ascertain whether these localities are areas of hydrothermal alteration and mineralization.

Two regional gravity surveys include the Rocky Boy's Reservation (Peterson and Rambo, 1967; Smith, 1970) (Figure 5). The scale of the surveys, however, is too small to permit correlation with the detailed geologic and aermagnetic data available for the reservation. Regional gravity features defined by the surveys can be correlated with regional structural features. The Bearpaw arch is defined by a positive gravity anomaly that noses sharply at the west end of the Bearpaw Mountains and extends some distance northeast of the range.

Gravity surveys have been the most effective of all geophysical techniques in establishing the shape and depth of intrusives (Bonini and others, 1971, p. 167). This geophysical method was successful in establishing the areal extent and depth of intrusive bodies in the Crazy Mountains and Little Rocky Mountains, Montana (Bonini and others, 1971, p. 172). A detailed large scale gravity survey of the reservation would be useful in determining subsurface features particularly those associated with former igneous activity.

MINERAL RESOURCES

General

A mineral resource is a concentration of materials in or on the earth's crust in such form that economic extraction of a commodity is currently or potentially feasible (U.S. Bureau of Mines and U.S. Geological Survey, 1976).

Mineral resources are classified according to geologic and economic availability. Thus resources are either identified--specific deposits whose location, quality, and quantity are known--or undiscovered. Undiscovered resources may be surmised to exist on the basis of geologic knowledge and theory. Identified resources are either economic--these are termed "reserves"--or subeconomic. Subeconomic resources are deposits that have been identified but must await changes in technology or price before they can be developed.

Mineral resources are commonly classified as energy (or fuel), metallic, or non-metallic (industrial) as in the following discussion.

Energy Resources

General

Energy resources on Rocky Boy's Reservation include natural gas, oil, coal, and uranium. Of these the most important is natural gas followed in importance by oil. Coal has been produced in the past. Uranium, although known to occur, has not been produced from reservation lands.

Natural Gas

The principal gas reservoir in the Bearpaw region is the Eagle Sandstone, but gas has been found in the Judith River Formation, Claggett Shale, and Telegraph Creek Member (Hearn, 1974). Occurrences of natural gas in the Eagle Sandstone are closely controlled by the distribution of lithofacies and the regional and local structures of the Bearpaw arch (Maher, 1969).

Gas formed in the Eagle Sandstone soon after its deposition; the original gas field in the Eagle Sandstone was probably huge, covering the entire Bearpaw arch (Maher, 1969). Much of the Eagle Sandstone was deposited in a littoral (beach) environment and is an excellent reservoir rock for oil and gas (Rice, 1976). The Eagle Sandstone above the Virgelle Sandstone Member contains three littoral sand bodies whose long axis trends northwest-southeast across the center of the Bearpaw Mountains (Figure 6A). These sands are separated by thin shale beds and intertongue with shale to the northeast and southwest of the Bearpaw region. Gas occurs widely throughout the upper sand and, where the upper unit is flooded with gas, in the middle sand, also.

In Eocene time upper Cretaceous and Tertiary strata, including the Eagle Sandstone, broke away from the rising Bearpaw arch and slid down the north and south flanks of the arch (Figure 6B) (Reeves, 1946). The principal zones of sliding were along clay beds in the Colorado Shale. As slippage took plate, faulting occurred in the beds overlying the thrust planes. Gas from the original field migrated into the newly formed structures, where it occurs today as local fields, each having its own reservoir seal and hydrostatic pressure. This feature is well illustrated by the Bowes gas field, where the reservoir boundaries are determined by faults (Sampsel, 1969) (Figure 7). The Bearpaw arch, and much of the pre-faulting Eagle gas field, was intruded by igneous rocks in middle Eocene time. The result of this complex history resulted in irregular zones of gas accumulation on the north and south sides of the arch (Figure 6B) that require intensive exploration to discover. The Tiger Ridge field, which extends onto the northern part of the reservation, is the largest field to be discovered to date.

The outlook for discovery of more gas on the reservation is good. The most prospective area lies southeast of Laredo, in T. 30 N., R. 15 E., where gas has already been discovered (Bayliff, 1975), and in T. 29 N., R. 14 E. where numerous fault blocks are present. Although much of the prospective area southeast of Laredo contains volcanic flows at the surface, drill holes show that sedimentary strata, including the Eagle Sandstone, underlie the volcanic rocks. Gravity sliding has moved igneous rocks over sedimentary terrain at many places in the Bearpaws so that even proximity to a stock may not rule out gas potential (Hearn, 1974). Gas has been found in sec. 14, T. 30 N., R. 15 E., 0.6 mile from the border of the Number One Mtn. stock. Dry holes in the vicinity of Boxelder do not make that area as attractive, but the test holes are somewhat sparse relative to the probable size of the targets. Because each fault block may contain a target, exploration possibilities will not be exhausted for some time.

Future gas discoveries will probably be in Upper Cretaceous formations in either structural or structural-stratigraphic traps. Structural traps that contain oil and gas will be difficult to locate because of complex geologic features (Hubbard and others, 1963, p. 2, 3, and 8). Possibilities of future discoveries of large oil and gas fields are not promising but small fields may be discovered.

Oil

The major occurrence of oil in the Bearpaw region is the Bowes field, located to the northeast of the reservation (oil occurs in 1 well 10 miles west of the reservation, and in 2 wells 4 miles northwest of Havre). Although the Bowes field does not have any extensions that approach the reservation, the geologic control on both oil and gas at Bowes provide insight to the type of target that may be sought elsewhere in northern Montana. The gas field at Bowes is in the Eagle Sandstone in discrete fault blocks (Figure 7), similar to the Tiger Ridge field. Below the main planes of sliding, the strata in the Bowes area assume a simple domal structure, and oil production is from a dome in the Jurassic Piper Formation (Figure 7). Thus two separate fields with different structural controls occur at Bowes: an upper gas field in the Eagle and a lower oil field in the Piper Formation. Several reports (Hunt, 1956; Johnson, 1958, Sampsel, 1969) provide extensive data on the geologic controls of the oil.

Oil in the Bowes field occurs in the middle and upper Piper Formation of the Ellis Group (Hunt, 1956). At Bowes the Piper has been divided into three members: the lowermost Tampico Shale Member (78 feet thick), the Firemoon Limestone

Member (76 feet thick), and the Bowes Member (50-60 feet of sandy limestone, sandstone, and shale). The upper 30 feet of the Firemoon Limestone and the lower part of the Bowes Member have porous oil producing zones. The upper part of the Bowes Member passes from nonporous shale and limestone in the southern part of the field to permeable sandstone and limestone in the northern part, so that the thickness of the oil-producing zone is much greater in the north. Such local sandstones in the upper Bowes Member are the source of production in the Dollard trend of Saskatchewan, also.

History and Production

On January 1, 1977, there were 10 shut-in gas wells on the reservation (Figure 8) with no pipeline facilities. Some of the gas wells may be an extension of the Tiger Ridge field. In 1976, the Tiger Ridge field produced 14,781,619 cubic feet of gas.

Bowes Oil and Gas Field.--The Bowes oil and gas field is 6 miles south of Chinook, 20 miles southeast of Havre, and about 4 miles northeast of the reservation. In 1924, the first gas well in the field was drilled but abandoned because the field lacked a pipeline. In 1926, four gas wells were completed, and a pipeline was laid into Chinook and Havre, Montana. By 1935, nine producing gas wells had been drilled. Initial flows ranged from 7 to 30 million cubic feet of gas per day. Initial pressures were from 250 to 300 psi with an average of about 200 psi and production depths ranged from 700 to 1000 feet. Gas production peaked in 1950, when 1.35 billion cubic feet were produced. Gas production in recent years and number of producing wells are given in Table 2.

Oil was discovered in 1949 when the Northern Ordinance No. 1 Guertzgen well was completed in sec. 2, T. 31 N., R. 19 E. Initial production was about 200 barrels of oil per day of 20º A.P.I. gravity oil from a depth of about 3400 feet. The productive zone is in the Sawtooth Formation of the Ellis Group. Additional wells were drilled and oil production peaked in 1953, when 1,025,261 barrels were produced. Initially, well production ranged from 100 to 400 barrels of oil per day. Oil production in recent years and number of wells are listed in Table 3.

Structure contours on the basal Jurassic Sawtooth (Piper) Formation indicate a roughly circular subsurface dome with a 3-½ mile diameter. It centers on the west sides of sec. 1, T. 31 N., R. 19 E., and sec. 36, T. 32 N., R. 19 E. with a closure of about 120 feet and no apparent faulting. The subsurface structure is about 2 miles east of a surface structure which is an irregular elongated faulted dome about 4 miles long and 2 miles wide.

TABLE 2

Gas production from Bowes field, Eagle Gas Zone (Upper Cretaceous)

Year	Number of producing wells	Production (thousand cubic feet)
1967	21	569,069
1968	19	497,649
1969	20	427,417
1970	18	343,620
1971	18	293,312
1972	18	280,333
1973	26	472,642
1974	26	372,346
1975	26	640,675
1976*	NA**	935,061

Source: Department of Natural Resources and Conservation of the State of Montana, Oil and Gas Conservation Division, Annual Reviews 1967 to 1975.

*Montana Oil and Gas Statistical Bulletin, Board of Oil and Gas Conservation, Vol. 25, 1976, No. 1-12, p. 1.

**NA (not available).

TABLE 3

Oil production from Bowes field, Sawtooth Formation (Middle Jurassic)

Year	Number of wells		Production (barrels)
	Producing	Shut-in	
1967	57	NA*	175,427
1968	58	NA	175,008
1969	52	NA	152,802
1970	52	NA	150,560
1971	43	33	137,902
1972	47	29	115,391
1973	41	29	85,798
1974	51	25	122,238
1975	51	25	127,793
1976**	52	NA	126,411

Cumulative production to Jan. 1, 1977, was 8,104,000 barrels. Reserves on Jan. 1, 1976, were 1,222,000 barrels. Water flood started in 1961 using water from the Madison Formation.

Source: Department of Natural Resources and Conservation of the State of Montana, Oil and Gas Conservation Division, Annual Reviews 1967 to 1975.

*NA (not available).

**Montana Oil and Gas Statistical Bulletin, Board of Oil and Gas Conservation, Vol. 25, 1976, No. 1-12, p. 2.

The producing oil zone (Sawtooth Formation, Middle Jurassic) has about 37 feet of net pay with an average porosity of 12 percent. The oil is confined in a structural trap with a partial water drive. A pilot water flood was started in 1961. By 1965 the entire field was water flooded. The productive zone underlies about 3760 acres and is about 3300 feet deep. The oil has an A.P.I. gravity of 19º.

Tiger Ridge Gas Field--Tiger Ridge, discovered in 1967, is the most productive gas field in the state of Montana. It is in T. 30 to 32 N., and R. 14 to 19 E., Hill and Blaine Counties. A small portion of the field extends into the northeastern part of the reservation. Production is from the Upper Cretaceous Judith River and Eagle Formations. The gas zones are structural-stratigraphic traps with depletion water drives. In 1975, about 39 percent of Montana natural gas production was from the Tiger Ridge field. Yearly production and number of wells are listed in Table 4.

Sherard Gas Field.--The Sherard gas field is about 14 miles south of the reservation. The field's first well was drilled in 1922 in sec. 17, T. 25 N., R. 17 E. The well crosses a fault and therefore some of the stratigraphic section is repeated. Estimated gas flows of 3 million and 20 million cubic feet of gas per day were obtained at depths of 1050 and 1750 feet respectively. The lower gas producing zone is in the Eagle sandstone. The well bottomed in Colorado shale at a depth of 2700 feet. About 15 years later, gas was also found in nearby wells which penetrated the Eagle Formation. All wells were shut in because a pipeline was not available (Perry, 1960, p. 53).

The field was reactivated in 1973 when a pipeline was completed to the Tiger Ridge gathering system, and production began in 1974. The field is a structural-stratigraphic trap with a volumetric water drive. Yearly production and number of wells are listed in Table 5.

TABLE 4

Gas Production from Tiger Ridge Field.

Year	Judith River Formation Number of wells Producing	Judith River Formation Number of wells Shut-in	Eagle Formation Number of wells Producing	Eagle Formation Number of wells Shut-in	Production (thousand cubic feet)
1968	0	1	0	33	0
1969	0	1	2	55	225,948
1970	1	5	9	94	466,985
1971	1	5	13	126	1,578,194
1972	6	0	93	26	5,104,476
1973	6	0	123	37	29,130,011
1974	6	0	139	12	19,452,541
1975	5	1	119	30	15,719,832
1976*	NA**	NA	NA	NA	14,781,619

Note: One oil well in the Sawtooth Formation is shut-in.

Source: Department of Natural Resources and Conservation of the State of Montana, Oil and Gas Conservation Division, Annual Reviews 1968 to 1975.

*Montana Oil and Gas Statistical Bulletin, Board of Oil and Gas Conservation, Vol. 25, 1976, No. 1-12.
**NA (not available).

TABLE 5

Gas Production from Sherard Field, Eagle Formation.

Year	Number of wells Producing	Number of wells Shut-in	Production (thousand cubic feet)
1973	0	12	None
1974	11	1	2,537,311
1975	8	1	2,353,832
1976*	NA**	NA	1,379,321

Source: Department of Natural Resources and Conservation of the State of Montana, Oil and Gas Conservation Division's Annual Reviews 1973 to 1975.

*Montana Oil and Gas Statistical Bulletin, Board of Oil and Gas Conservation, Vol. 25, 1976, No. 1-12.
**NA (not available)

Gas has recently been discovered in the Bullwacker area which is northwest of the Sherard field, and about 5 miles south of the reservation. Production from the Judith River and Eagle Formations averages about 190 million cubic feet per month.

Transportation and Markets

All gas wells on the reservation are shut-in because pipeline transportation is not available. The gas will find a ready market when the necessary pipelines have been completed.

Environmental Aspects

Of all the fossil fuels, natural gas is the least disruptive to the environment, both in its extraction and consumption. However, the discovery and production of gas disturbs and changes the local landscape. Most disruptions and landscape changes are caused by roads being built to drilling and storage sites and pipeline construction.

All well sites should be properly graded and planted with grasses that will thrive in the local environment. Tanks containing salt water (usually produced with gas) should be enclosed by dikes. Salt water should be disposed of in an environmentally acceptable way. Experienced personnel can keep ground disturbance and air pollution to a minimum.

Coal

General.--Coal is present on the reservation in three geologic formations: the Upper Cretaceous Eagle Sandstone (base of the Montana Group), the Upper Cretaceous Judith River Formation (middle of the Montana Group), and the Paleocene Fort Union Formation (base of the Tertiary sedimentary rocks) (Figure 9; Table 1). In the southern and southeastern Bearpaw Mountains, coal is present in the Hell Creek Formation (uppermost Cretaceous) (Hearn and others, 1964; Bryant and others, 1960). Production on the reservation has come from the Rocky Boy and Blue Pony mines (Figure 1).

Deposits.--The northeastern part of the Big Sandy coal field extends into the reservation (Bowen, 1912, pl. XXI, p. 373). The coal occurs in down-faulted blocks where Tertiary sedimentary rocks have been protected from erosion.

The most economically significant coal beds are in the Fort Union Formation (Figure 9) which underlies about 2,580 acres of reservation land. An additional 2,940 acres of Fort Union Formation are directly overlain by the noncoal-bearing Wasatch Formation. At the Rocky Boy mine (Figure 1 and Figure 9), in sec. 31, T. 29 N., R. 15 E., the coal bed averages about 4 to 4-½ feet thick. Locally, it thickens to 5-½ feet but contains bands of impure coal. In sec. 25, T. 29 N., R. 14 E., a 52-inch bed was mined at the Blue Pony mine (Figure 9 and Figure 10) (Osgood, 1932, p. 99). A 2-foot bed crops out in NE¼ sec. 10, T. 28 N., R. 14 E., about 3-½ miles southwest of the Rocky Boy mine (Bowen, 1912, pl. XXI). The coal bed dips 15-20º SE. at the Rocky Boy mine and 28º SE. at the Blue

Pony mine. The Blue Flame mine about 4 miles northwest of the Rocky Boy mine (Figure 9 and Figure 10) but outside the reservation is probably also in the Fort Union Formation.

Resources.--The coal resources in the vicinity of the Rocky Boy and Blue Pony mines were estimated by projecting the beds between known exposures (Figure 10) (Hubbard and others, 1963, p. 4). By assuming an average bed thickness of 4.5 feet, the resource is estimated to be 1,250,000 tons. Additional resources may be present in underlying beds. Also, coal beds may be present in areas where the Fort Union Formation underlies the Wasatch Formation (Figure 9), but these would probably be too deep to be of economic interest at this time.

The coal in the Eagle and Judith River Formations is in thin beds, generally less than 3 feet thick, separated by layers of rocks. Coal just above the Virgelle member of the Eagle sandstone is exposed along the Missouri River and Little Sandy Creek, southwest of the reservation where as much as four feet of coal was measured (Lindvall, 1956). A coal bed as thick as 2 feet was measured in the upper and lower parts of the Judith River Formation along Little Sandy Creek (Lindvall, 1956) and along Big Sandy Creek in sec. 12, T. 27 N., R. 13 E., and secs. 7 and 8, T. 27 N., R. 14 E. (Bowen, 1914a). Coal is also present in the Judith River Formation in the Cleveland area, northeast of the Bearpaw Mountains (Bowen, 1914b). In view of the wide extent of the coal beds, it seems likely that the Judith River coal beds extend onto the reservation. Coal in the Eagle sandstone may extend onto the reservation also, but this is uncertain. Some of the most promising areas for coal occurrence on the reservation have been located using the detailed geologic maps (Pecora and others, 1957a, 1957b; Kerr and others, 1957; Stewart and others, 1957; and Lindvall, 1956, 1961) of the area (Figure 7). Glacial deposits cover areas of possible coal occurrence on the reservation, making location in the field difficult. The thinness of the beds and their separation by barren rocks makes it unlikely that these coals could ever be used except for local heating.

Characteristics.--The rank of the Fort Union coal, as indicated by analyses of samples from the Rocky Boy and Blue Pony mines (Table 6) is high volatile bituminous C. It decreases in a westerly direction to subbituminous A at the Mack and Mackton mines. Coal in the Judith River and Eagle Formations is subbituminous where exposed off the reservation.

Underground Mining Methods.--The last operating mine on the reservation was the Rocky Boy mine. A room and pillar system was used and main headings were driven down dip (Figure 11). Rooms were driven perpendicular to the main headings along the strike of the bed. The main heading intersected a fault 340 feet from the portal. In 1963, some pillars were re- moved and the mine was abandoned. It underlies about 7 acres. In 1962, a second mine was opened nearby but it was abandoned in 1965 because of an unstable roof and an insufficient demand for coal.

The reservation's known coal resources are insufficient to support large underground mines, since each requires a minimum reserve of 10-20 million tons. Thus, probably only small mines using the room and pillar method will be practical. The steep pitch of the coal beds would make underground mining more difficult. Much of the reservation's coal cannot be mined using equipment that has been developed for flat-lying beds. Continuous mining machines, and other mobile equipment, are not practical where beds are inclined more than 10 to 14 percent (5.7º to 8.0º). The coal bed at the Rocky Boy mine dips 15-20 degrees. Where standard equipment has been used in beds pitching as much as 20 percent (11º) operational and maintenance problems have been excessive (Schroder, 1913, p. 363). Numerous faults and igneous dikes will require that detailed structure maps of the coal beds be made prior to underground mining. Specialized, highly-skilled labor, which may be scarce or unobtainable in the reservation area, will be necessary.

Surface Mining Methods--Small-scale surface mines that would supply local markets may be developed in areas containing shallow coal beds. The ratio of overburden depth to coal thickness (stripping ratio) averages about 11 to 1 in United States surface coal mines (Averitt, 1975, p. 55). Using this ratio as a guide, the maximum overburden depth in the vicinity of the Rocky Boy mine would be limited to about 50 feet. Stripping ratios in the large surface mines in Montana range between 3 and 5 to 1. This ratio would limit overburden depth to 15 to 25 feet near the Rocky Boy mine.

Surface mining costs are only one-fourth to one-third that of under- ground mining (Katell and others, 1976a, p. 5; Katell and others, 1976b, p. 5). Also, surface mining is safer, and coal recovery is higher, about 90 percent. It appears this would be the best method for developing the reservation's coal resources, assuming suitable deposits are present.

Additional coal can be recovered by auger mining following conventional surface mining. With this method, an auger machine bores holes up to 200 feet deep parallel to the coal bed. Capital costs are low and productivity is high, but recovery is low. Where the dip of the bed is not excessive, coal can also be recovered by punch mining, which is a series of entries driven into the bed by a continuous miner (Phelps, 1973, p. 392).

Uranium

Uranium occurs with niobium and rare earths in carbonatite veins at the head of Big Sandy Creek, in sec. 19, T. 28 N., R. 16 E. The occurrence has been estimated to contain many thousands of tons of rock containing 0.2 percent U_3O_8 and much more lower grade rock (U.S. Geological Survey, unpublished data).

Sandstone-type deposits containing uranium may be found in the Wasatch, Fort Union, and Hell Creek Formations; coal deposits in the Fort Union, Judith River, and Eagle Formations may contain uranium (Armstrong, 1957, p. 219). Many areas underlain by these formations are covered by thick overburden, which makes geiger and scintilation counters ineffective. In areas of this type, ground water sampling has been effective in evaluating uranium potential (Denson, 1959, p. 7). Geochemical exploration may also be useful in the grassy and timber covered areas of the Bearpaw Mountains. Pegmatites are scattered throughout parts of these mountains and uranium minerals sometimes occur in pegmatites (Page, 1960, p. 12).

The increased demand and higher price for uranium has stimulated exploration. Attention is now being directed to low grade exploration targets that previously were of little interest. Resources with as little as 0.01 percent U_3O_8 may soon become economical (Lieberman, 1976, p. 435). Several years ago, the Bearpaw Mountains were explored for high-grade ore (more than 0.20 percent U_3O_8) and now should be reexamined for 0.03 to 0.05 percent material (Armstrong, 1975, p. 106).

Metallic Mineral Resources

General

Two areas of known metal occurrence on and near the reservation are at Rocky Boy stock and at scattered localities extending from Beaver Creek northeasterly to White Pine Canyon and to the east side of Clear Creek, off the reservation (Figure 12). All of these mineral occurrences are within the igneous rocks of the Bearpaw.

Columbium

Columbium and other valuable elements are found in carbonatite- alkaline rock complexes. About 100 of these complexes have been discovered worldwide with less than half containing columbium. About 20 contain economic deposits (Dc Kun, 1962, p. 382).

A carbonatite-alkaline rock complex containing columbium is in sec. 19, T. 28 N., R. 16 E. on the north fork of Big Sandy Creek, approximately 22 miles east of Big Sandy. Dikes and veins occur in Porphyritic syenite of the Rocky Boy stock and extend into nearby monzonite and shokinite.

At the Vermiculite or Bearpaw mine (Figure 13 and Figure 14), several short adits were driven and at least two shafts sunk from 1908 to 1930 to explore for gold, silver, lead, copper, and zinc (Allport, 1930, p. 1; Heinrich, 1949, p. 46). No significant precious or base metal deposits were found but the area later attracted renewed interest because radio- metric surveys indicated the presence of radioactive minerals. In 1957, exploration geologists from Texas Instruments, Inc. collected samples from the old adits and drilled several diamond drill holes. No economic deposits were found. Additional drilling by Union Carbide Nuclear Corp. in 1968 did not find ore.

Mineral occurrences associated with the largest dike, the Number One deposit, have received the most attention (Figure 13 and Figure 14). This dike is steeply dipping, about 15 to at least 50-feet thick, more than 500 feet long, and 900 feet deep (Pecora, 1962, p. 93). A 3- to 5-foot selvedge (zone) along the highly brecciated northern contact contains a fine-grained mixture of apatite, zircon, and pyrochlore. The pyrochlore contains an estimated 15 to 20 percent U_3O_8, 25 to 35 percent Cb_2O_5, 1 to 2 percent Ta_2O_5, more than 1 percent yttrium, and minor cerium, lanthanum, other rare earth elements, and thorium (Texas Instruments, 1957, p. 3).

The Number One adit was driven through the selvedge and two drifts were driven 10 and 15 feet along the contact. An analysis of a sample from the selvedge is listed in Table 7. About 30 tons of selvedge material were stockpiled at the adit entrance and a grab sample was analyzed by the U.S. Bureau of Mines in 1962 (Hubbard and others, 1963, p. 13). This analysis is also listed in Table 7.

The 1.5-foot thick selvedge at the southern contact is much less mineralized (Pecora, 1962, p. 93). A 9-foot channel sample collected there contained only 0.016 percent uranium (Table 7). Low grade material from the Number One adit contained 0.17 percent Cb_2O_5 (Hubbard and others, 1963, p. 13). Syenite from the face of the Number One adit assayed 0.04 percent Cb_2O_5 (Pecora, 1962, p. 97).

If the thickness of the selvedge at the north contact is assumed to average 4 feet over the known length and depth of the mineralized structure, it contains approximately 200,000 tons of rock with about 1,000,000 pounds of columbium and 500,000 pounds of uranium. The selvedge has been described as late fracture fillings and replacements in both the porphyry country rock and dike material (Texas Instruments, 1957, p. 3). Successful mining of this selvedge would require a thorough understanding of its structural control.

Many additional thousands of tons of low-grade material assaying 0.06 to 0.17 percent Cb_2O_5 are present in or near the Number One deposit.

TABLE 7

Analyses of Samples from Vermiculite Mine Number One Deposit, Rocky Boy's Indian Reservation

Location	U_3O_8 (percent)	Cb_2O_5 (percent)	Ta_2O_5 (percent)
Northern selvedge, No. 1 adit**	0.204	0.306*	0.020*
Northern selvedge, No. 1 adit***	0.13	0.50	less than 0.20
Southern selvedge**	0.016	0.024*	0.002*
Low grade meterial from No. 1 adit*** ****	trace	0.17	less than 0.05

*Based on U:Cb:Ta ratio of 10:15:1 estimated by Texas Instruments, Inc.

**1957 Prospecting Program, Permit Units 2 and 3, Rocky Boy's Reservation, Montana, Texas Instruments, Inc.

***Mineral Resources and Their Potential on Indian Lands, Rocky Boy's Reservation, 1963, U.S. BuMines Preliminary Rpt. 148.

****U.S. BLM Triangle Planning Unit report, 1975.

Beneficiation tests of pyrochlore-bearing material from the Number One deposit were conducted by the U.S. Bureau of Mines in 1962 (Hubbard and others, 1963, p. 13). Very little concentration was accomplished. However, columbium ore from a carbonatite deposit is successfully beneficiated by a modern process at St. Honore, Quebec, Canada (Mining Magazine, 1976, p. 501). The ore is ground and much barren material is removed in a carbonate "pre-flotation" stage. A two-stage flotation process further concentrates the pyrochlore and removes the majority of the sulfides. The concentrate is next leached with hydrochloric acid and a final flotation step removes most of the remaining sulfides. This process may be applicable to the pyrochlore-bearing material from the Number One deposit because ore from the Canadian deposit is similar. Laboratory tests are necessary to determine if modern beneficiation processes can effectively treat pyrochlore bearing material from the reservation.

No columbium ore has been mined in the United States since 1959. Most columbium mineral concentrates are imported from Brazil. The reported price for pyrochlore concentrate in 1976 was $1.85 per pound of contained Cb_2O_5 (Stipp, 1977, p. 44). The price of imported columbium mineral concentrates increased 32 percent in 1976 over 1975 year-end prices. Domestic demand for columbium is expected to increase at an annual rate of about 5 percent through 1980. The increased demand and price for columbium (and uranium) could stimulate renewed interest in the resources on the reservation.

Tantalum

Pyrochlore from the Number One deposit is reported to contain about 1 pound of tantalum for each 15 pounds of columbium (Texas Instruments, 1957, p. 3). Thus, tantalum could be a valuable constituent in the columbium- and uranium-bearing concentrate. However, columbium-tantalum ratios in pyrochlore ranging from 50 to more than 1,000 to one are more common. Because of analytical difficulties, some reported low ratios are doubtful; more precise analyses have established very high ratios in several carbonatite pyrochlores (Deans, 1966, p. 399). Therefore, additional sampling and analysis of the reservation's pyrochlore deposits is advisable.

Rare Earths

Rare earth minerals are associated with the carbonatite-alkaline rock complex at the head of the Big Sandy Creek. Two rare earth carbonate minerals, burbankite and calkinsite, have been obtained from test pits about 1000 feet southwest of the entrance in the Number One adit (Pecora and Kerr, 1953, p. 1171). Many veinlets and disseminations rich in burbankite were intersected in a drill hole at depths between 283 and 375 feet (Texas Instruments, 1957, p. 4). The drill hole collar is about 200 feet east of the entrance to the Number One adit.

Minerals containing rare earth elements are in abundant domestic and world supply. To support large-scale development of the reservation's rare earth resources would require the finding of large deposits that could be mined by low-cost open pit methods. However, burbankite crystals as large as 3 centimeters have been found on the reservation and mineral specimens for collectors might be mined economically on a small scale.

Gold, Silver, and Lead

In the 1860's, some gold was placer mined from gravel bars along creeks draining the Bearpaw Mountains. Prospecting for lode deposits began in the 1870's. A few deposits were discovered, most of which were east of the reservation.

The most significant discovery was 15 miles east of the reservation where a vein containing argentiferous galena was found in 1888. The nearly vertical vein, which is from 4 to 5 feet wide and contains several highly mineralized zones 2 to 6 inches wide, has been mined at the O'Hanlon (Bear's Paw, Linda) mine. A hand-picked shipment of ore contained 50 ounces of silver per ton, 50 to 60 percent lead, and a little gold (Pepperberg, 1909, p. 141). This 7-ton ore shipment is the only known production from the Bearpaw Mountain area. The mine was inactive in 1975 (Lawson, 1976, p. 4).

The best known mineralized area (discussed earlier under columbium) is in the center of the Rocky Boy stock (Pecora and others, 1957; Pecora, 1956, 1962). A plug of potassic syenite at SE¼NE¼ sec. 9, T. 28 N., R. 16 E. in the stock contains abundant disseminated pyrite and pyrrhotite over an area of about 1,000 by 1,500 feet. Rock and soil samples from the same area contained anomalous amounts of copper, lead, and zinc (U.S. Geological Survey, unpublished data). The porphyry is extensively sericitized and cut by veins of altered biotite and vermiculite; carbonatite veins cut the syenite and adjacent shonkinite.

The scattered mineral occurrences at the Rainbow prospect to the northeast are metalliferous veins and fracture zones in volcanic and intrusive rocks (Pepperburg, 1910b; Pecora and others, 1957a). Most of the veins and mineralized fractures are thin and discontinuous; the most common ore mineral is galena, and the principal gangue minerals are pyrite, calcite, quartz, and barite. Silver is generally present in the galena, and gold and copper have been reported in assays of ore from prospects at the head of White Pine Canyon and at some prospects east of Clear Creek (Pepperburg, 1910b).

Mines and Prospects

Silver King.--The Silver King (White Pine Gulch) prospect is one of several at the head of White Pine Canyon about 4 miles east of the reservation. Veins of argentiferous galena are commonly less than one inch wide and discontinuous. A reported assay is 63 ounces of silver and about 2 ounces of gold per ton, and 23 percent lead (Pepperberg, 1909, p. 145).

Rainbow Claims.--The Rainbow claims are on the reservation in NW¼NE¼ sec. 10, T. 28 N., R. 16 E. (Figure 1 and Figure 12). An adit on the west side of Beaver Creek is near a shonkinite-syenite contact. Another adit in the east canyon wall of Beaver Creek is on the contact between shonkinite and metasedimentary rocks. The adit was driven about 100 feet on a small vein that ranges from 1- to 18-inches thick, strikes N. 50º E., and dips from 75 to 80º southeast. The vein contains galena in two, one-half to 6-inch thick bands. Six selected samples assayed from 7 to 26 ounces of silver and 0.04 to 0.12 ounces of gold per ton, and 19 to 80 percent lead (Allport, 1928, p. 4). In 1975, all adits were reported caved and the workings overgrown (Gibsby, 1975).

The thorium content of the mineralized zone associated with the Rainbow claims is estimated to average no more than a few tenths of one percent, but selected samples may contain several percent (Jarrard, 1967. p. 49).

Big Sandy Prospects.--The porphyritic syenite at the head of Big Sandy Creek typically contains 2 to 6 percent disseminated sulfides which are mostly pyrite and pyrrhotite, with minor copper, lead, and zinc (Pecora and others, 1957). The syenite outcrop covers an area of about 1000 by 1500 feet. It is cut by many pegmatites and veins which contain larger proportions of galena and chalcopyrite to iron sulfides than the porphyritic syenite. Allport (1930, p. 4) judged prospects in the area to be of doubtful value. Analyses of samples from two adits are as follows:

Sample	Silver (oz/ton)	Gold (oz/ton)	Copper (percent)	Lead (percent)	Zinc (percent)
1	0.40	0.01	0.40	3.00	Trace
2	Trace	Trace	0.20	Trace	0.30

Nonmetallic Mineral Resources

General

Nonmetallic mineral resources on the Rocky Boys Reservation are limited. The following discussion is to point Out that a few resources may have potential if industrial development takes place nearby.

Bentonite

Bentonite beds occur in three stratigraphic units on the reservation and vicinity, the Niobrara Shale Member of the Colorado Shale, and the Claggett and Bearpaw Shales of the Montana Group (Berg, 1969). The Niobrara Shale contains many bentonite beds as much as 18 inches thick, but the overburden generally exceeds 50 feet, making them uneconomic. In the Big Sandy area, numerous bentonite beds occur in the lower 100 feet of the Claggett Shale but none of these exceed 18 inches thick and all are covered by 50 feet or more of overburden (Lindvall, 1956). The lower part of the Bearpaw Shale contains numerous bentonite beds, also, .and tests on samples from southeast of the Bearpaw Mountains approached minimum requirements for use in foundry molding sand (Berg, 1969).

Clay and Shale

Many beds of clay and shale are present. Samples collected near the reservation were tested to determine their suitability for the manufacture of ceramic products and expanded aggregate (Sahinen and others, 1960, P. 20, 25). Many were found unsuitable because their bentonite content is high.

Clay from the River Formation has been used for manufacturing common brick and face brick near Havre. Ceramic products and expanded aggregate are commonly made from clays associated with coal beds.

Vermiculite

Vermiculite has been mined from a deposit at the head of Big Sandy Creek (Figure 1 and Figure 14). Mining began in 1929 but terminated after a few years. Vermiculite is exposed in an open cut and several prospect pits (Figure 13 and Figure 14). lt occurs in several dike-like structures which are nearly vertical and range from 2 to 3 inches to nearly 4 feet in width (Perry, 1948, p. 31). Some of the vermiculite expands sufficiently when heated and is considered good quality. However, the amount of this material is very limited and found principally near the surface. A few feet below The surface, the vermiculite grades into unaltered biotite, which has no commercial value.

Phosphate

Phosphate occurs at two locations. One is in the form of phosphate nodules and the other is apatite in syenite.

Phosphate nodules are present in the lower 30 feet of the Colorado Shale of the Bearpaw Mountains region (Pecora and others, 1962). The nodules contain as much as 34 percent P_2O_5, but they are widely dispersed in shale. It is unlikely that the nodules will ever be a resource.

The average apatite content of some of the syenite near the head of Big Sandy Creek is on the order of 0.1 to 1 percent; it is higher in the more highly sericitized syenite (Pecora, 1962, p. 88). These analyses indicate that the syenite cannot be considered an economic source of phosphorus at this time.

Sand and Gravel

The principal sources of sand and gravel on the reservation are along Big Sandy Creek and its tributaries (Figure 15). Local deposits of glacial outwash in the hills along Big Sandy Creek generally contain well-sorted sand and gravel, and these have been the principal source for local use. Relatively large areas of glacial outwash, covering several square miles, occur east and south of Boxelder; numerous other deposits are present along the west side of Big Sandy valley. The alluvium of the valley floors of Big Sandy Creek and its tributaries may contain local deposits of sand and gravel of commercial value, and a few pits appear to have been developed in the alluvium. generally the alluvial valleys contain much silt, however, and this covers any deposits of sand and gravel and diminishes their quality.

Sand and gravel production in Chouteau County in recent years averaged 182,000 tons per year with a value of $0.94 per ton; in Hill City it averaged 132,400 tons per year With a value of $0.91 per ton. The low value per ton, high transportation costs, and the abundance of other deposits in Mountain limit reservation sand and gravel to local use. This situation is not expected to change.

Nepheline Syenite

A ring structure of nepheline syenite associated with a carbonatite intrusive is in secs. 18 and 19, T. 28 N., R. 16 E. (Pecora and others, 1957). Nepheline syenite has been mapped in secs. 20, 21, 29, and 30, T. 28 N., R. 16 E. (Pecora, 1942, p. 400). An occurrence has been reported in sec. 23, T. 28 N., R. 15 E. (Hubbard and others, 1963, P. 9).

Most of the nepheline syenite consumed in the United States is imported from Canada and used by the glass and ceramics industry. Their specifications require a nepheline content of at least 20 percent. Alumina must exceed 23 percent and the alkali content must be over 14 percent; Fe_2O_3 cannot be over 0.1 percent and other metallic contaminants must be very low (Minnes, 1975, p. 862). An average analysis of several nepheline syenite samples from the reservation (Table 8) indicates it does not meet these specifications. However, quality can usually be increased by modern beneficiation processes. Sulfides and other contaminants can be removed by flotation, and the iron content reduced by magnetic separators. Nepheline syenite deposits associated with carbonatites, however, show little promise for utilization by the glass and ceramics industries because of variable composition, excessive rare earth, halide, and other trace element contaminants (Hinnes, 1975, p. 875).

TABLE 8

Average Mineralogical Composition and Chemical Analysis of Nepheline Syenite, Rocky Boys Indian Reservation.

Average mineralogical composition		Average chemical analysis	
Mineral	Percent	Compound	Percent
Pyroxene	24	SiO_2	49.7
Olivine	2	Al_2O_3	14.0
Biotite	14	FeO	4.8
Sanidine	35	Fe_2O_3	3.7
Nepheline	18	MgO	4.6
Others	7	CaO	6.7
		Na_2O	2.7
		K_2O	9.2
		TiO_2	.9
		P_2O_5	.9
		MnO	.l
		H_2O	1.0
		CO_2	.3
		SO_3	.5
		BaO	.3

Source: Mineral Resources and Their Potential on Indian Lands, Rocky Boy's Reservation, 1963, U.S. BuMines Preliminary Report 148.

Stone

Various rock types found on tile reservation might be suitable for crushed stone or riprap. In the event a market develops for such material (Figure 16), the variety and quantity of the material available would probably satisfy all demand.

RECOMMENDATIONS FOR FUTURE WORK

Natural gas is the reservation's most important mineral resource. Geological and geophysical surveys should be conducted to define prospective locations for exploration drilling. Particularly favorable areas are in T. 30 N., R. 14 E., and T. 29 N., R. 15 E.

Some of the reservation's coal resources can best be developed by surface mining methods. An exploration program is recommended to locate areas suitable ton surface mining. Fort Union coal beds in the southwestern part of the reservation are the most promising.

Additional sampling and analyses are recommended to determine coal quality especially in areas that might be mined in the future.

Uranium and niobium reserves at the head of Big Sandy Creek should be determined accurately by detailed study of logs, core, and assays from previous drilling programs, by additional assays on core if available, and, if additional data are needed, by drilling and assaying in the mineralized area outside the Number One deposit. The grade and tonnage of low-grade (subeconomic) ore should be estimated separately from reserves.

The various indications of base and precious metal mineralization, including magnetic anomalies, should be checked in the field for evidence of the minerals. If any of these areas do have indications of extensive mineralization at the surface, they should be explored by geochemical surveys, and if these are positive, by drilling and assaying.

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Table 6.--Analyses of coal from mines on the Rocky Boy's Indian Reservation and vicinity

				Proximate analyses, percent				Ultimate analyses, percent					Heat content	Ash softening
Mine	Bed	Formation	Location	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen	(BTU/lb)	temp.(F°)
Blue Pony 1/	Lance	Lance	Sec. 25, T.29N., R.14E.	7.9	34.5	46.6	11.0	0.7					10,740	2,280
Rocky Boy (1950) 2/			Sec. 31, T.29N., R.15E.	6.3	40.5	48.9	10.6	1.0					11,260	
Rocky Boy (1958) 3/			Sec. 31, T.29N. R.15E.	5.6	35.2	46.3	18.5	1.1					10,970	2,290
Mack 1/	Un-named	Fort Union	NE1/4 SE1/4 Sec. 18, T.28N. R.14E.	14.9	34.6	44.1	6.4	.5	5.4	58.6	0.9	28.2	9,940	
Mack-ton 1/	Big Vein	Fort Union	NW1/4 SW1/4, Sec. 18, T.28N., R.14E.	13.0	36.3	40.1	10.6	.5					9,620	2,230
Mack-ton 1/	do	do	do	12.4	36.9	35.8	14.9	.7					9,090	2,030
Mack-ton 1/	do	do	do	12.1	34.7	41.7	11.5	.8	5.3	55.9	.7	25.8	9,600	
Schew 4/			SE NE Sec. 28, T.28N., R.14E.	21.2	31.4	36.4	10.9	.9					8,244	
Nygard 1/	Big Sandy	Lance	T.28N., R.14E., (Sec. unknown)	14.4	33.2	46.2	6.2	.6	5.7	59.3	.9	27.3	10,140	2,290
Van Bus-kirk 1/	Un-named	Judith River	Sec. 20, T.25N., R.16.E.	19.8	30.8	34.5	14.9	.9					8,240	
Leh-fehlt 1/	Eagle	Eagle	Sec. 23, T.24.N., R.15E.	13.9	32.0	36.7	17.4	.8					8,570	
Deda 1/	Un-named	Eagle	Sec. 6, T.24.N., R.13E.	18.2	29.3	41.2	11.3	.8	5.6	53.2	1.2	27.9	9,120	

1/ BuMines Tech. Paper 529.
2/ BuMines Bull. 516.
3/ BuMines Rept. Invs. 5489.
4/ Montana Bureau of Mines & Geol., Special Publication 43.

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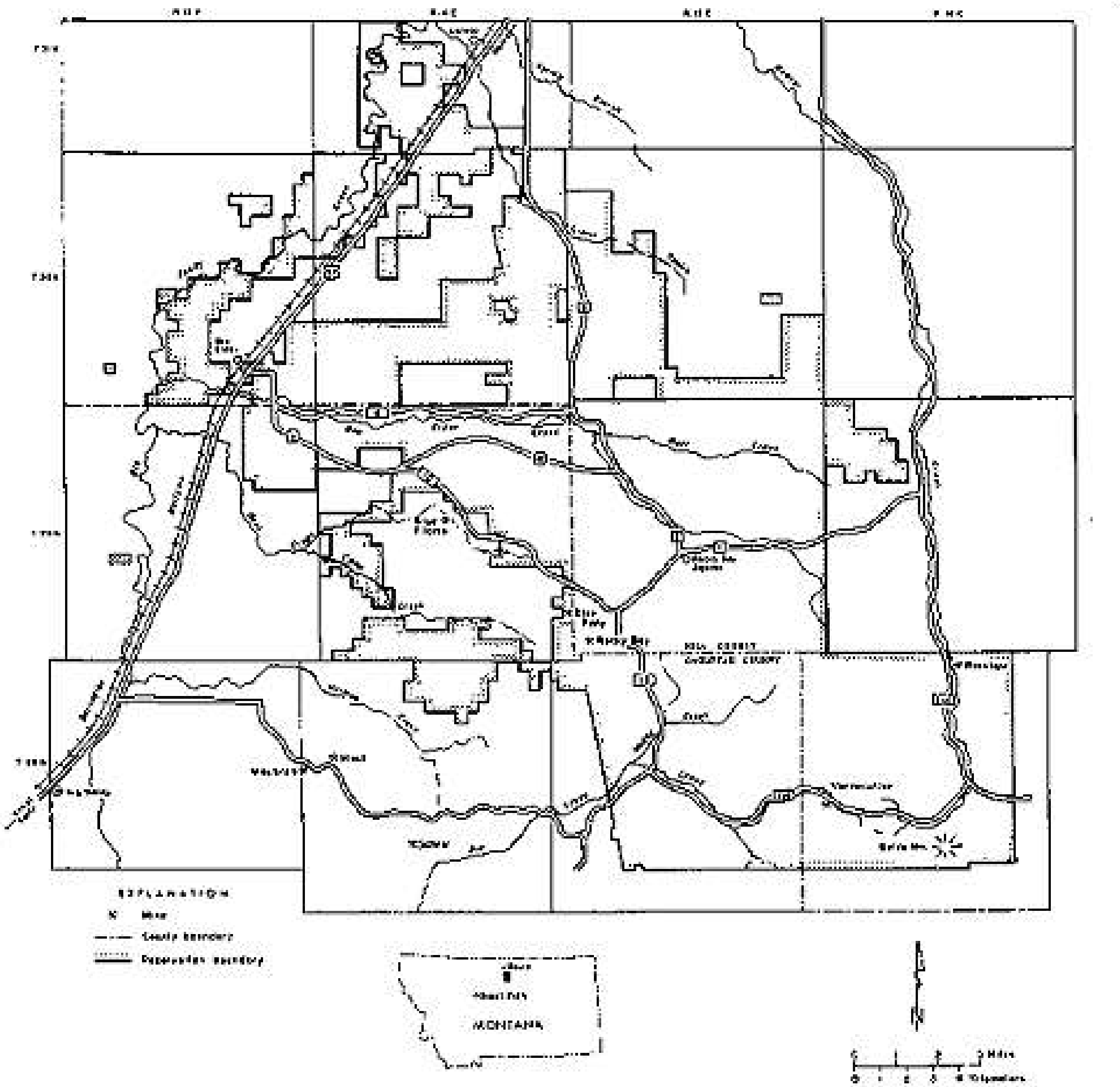

Figure 1. Index map showing location of mines on Rocky Boy's Indian Reservation, Montana (adapted from Bureau of Indian Affairs land status map, 1973).

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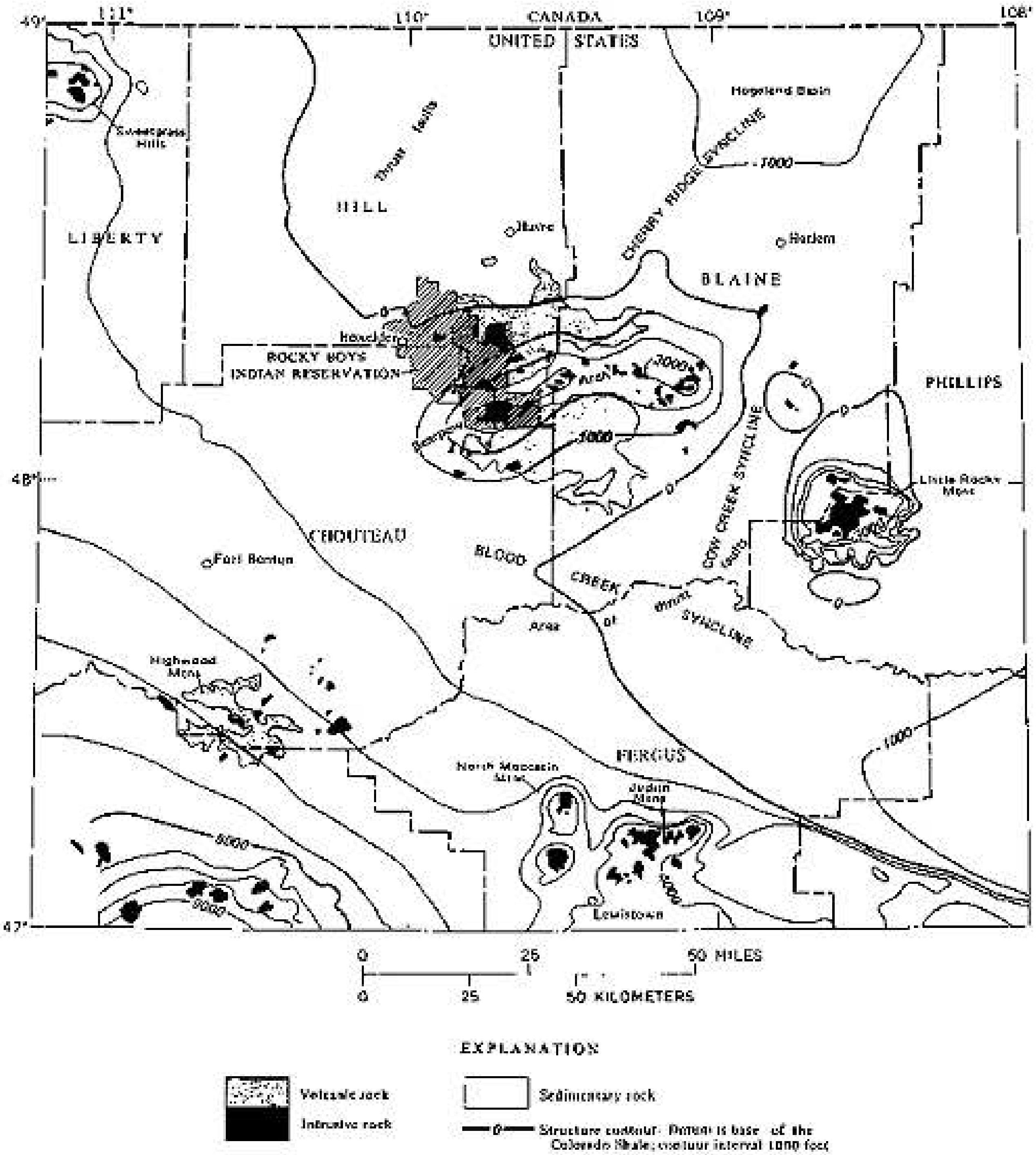

Figure 2. Map showing regional geologic and structural setting of the Rocky Boy's Indian Reservation, North Central Montana (from Dobbin and Erdmann, 1955).

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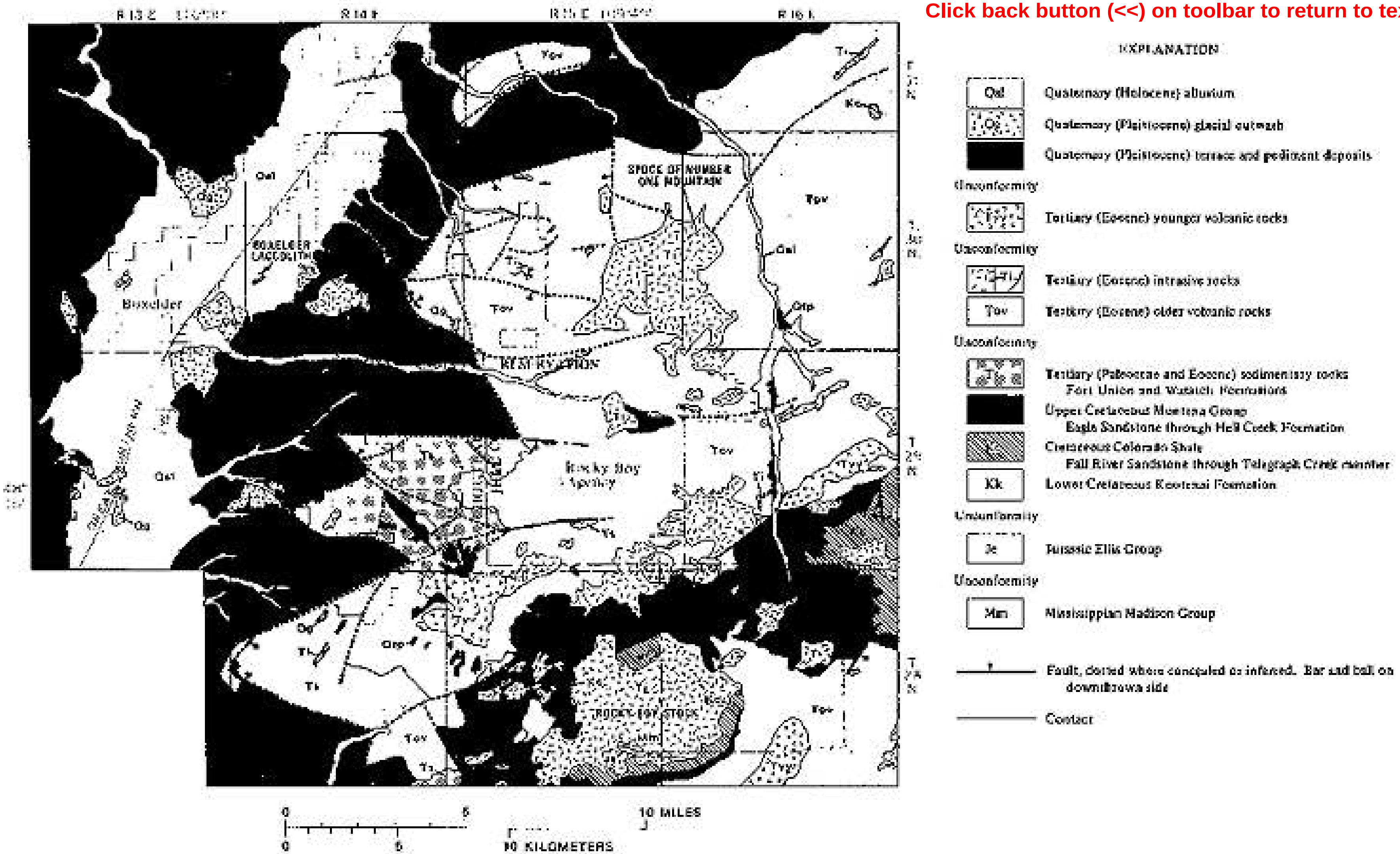

Figure 3. Geologic map of the Rocky Boy's Indian Reservation and vicinity, Montana (compiled from Pecora and others, 1957a, 1957b; Kerr and others, 1957; Stewart and others 1957; Lindvall, 1956, 1961; and Hearn, 1974).

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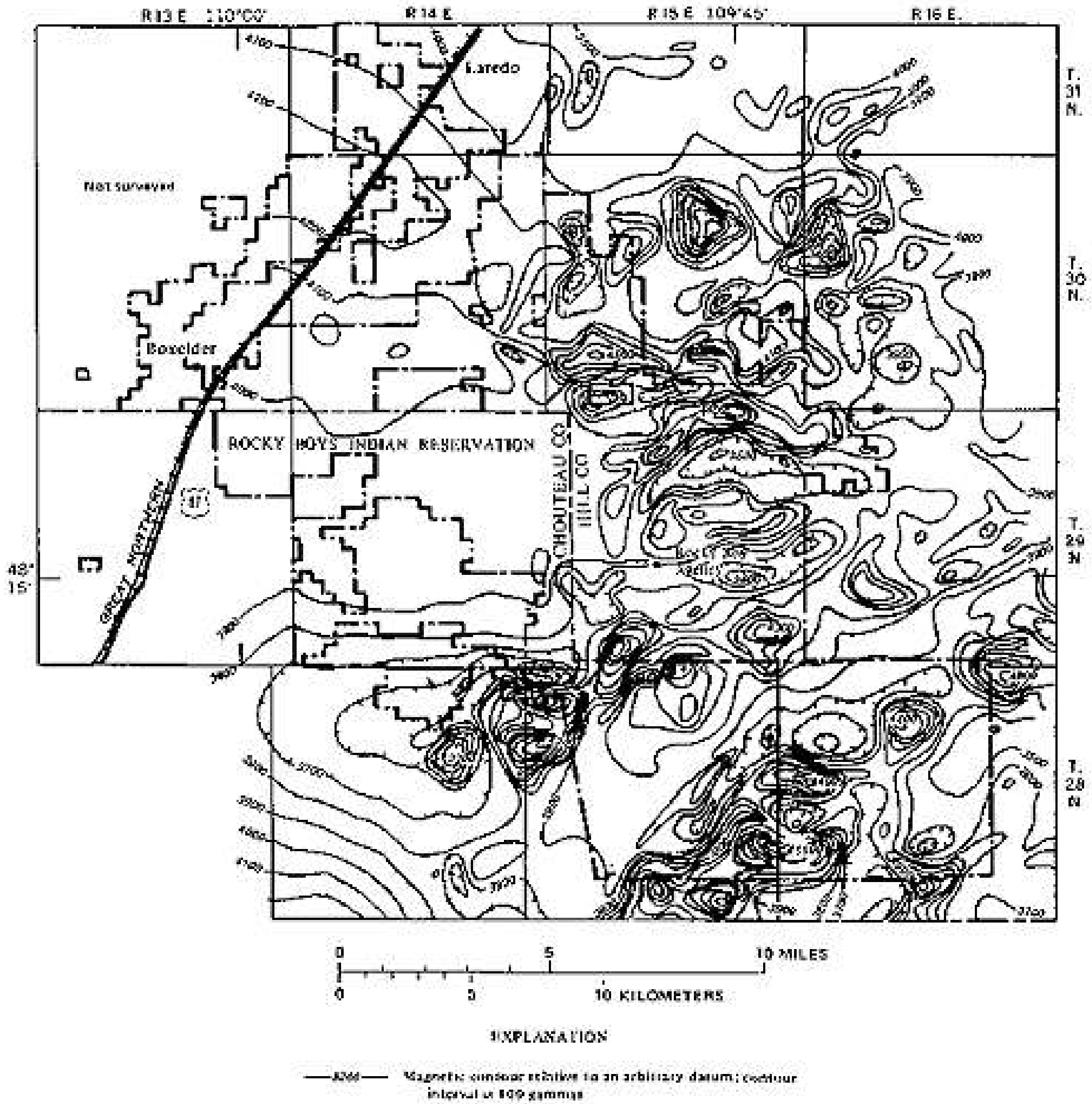

Figure 4. Aeromagnetic map of Rocky Boy's Indian Reservation and vicinity, Montana (compiled from Balsley and others, 1957a, 1957b, 1957c, 1957d).

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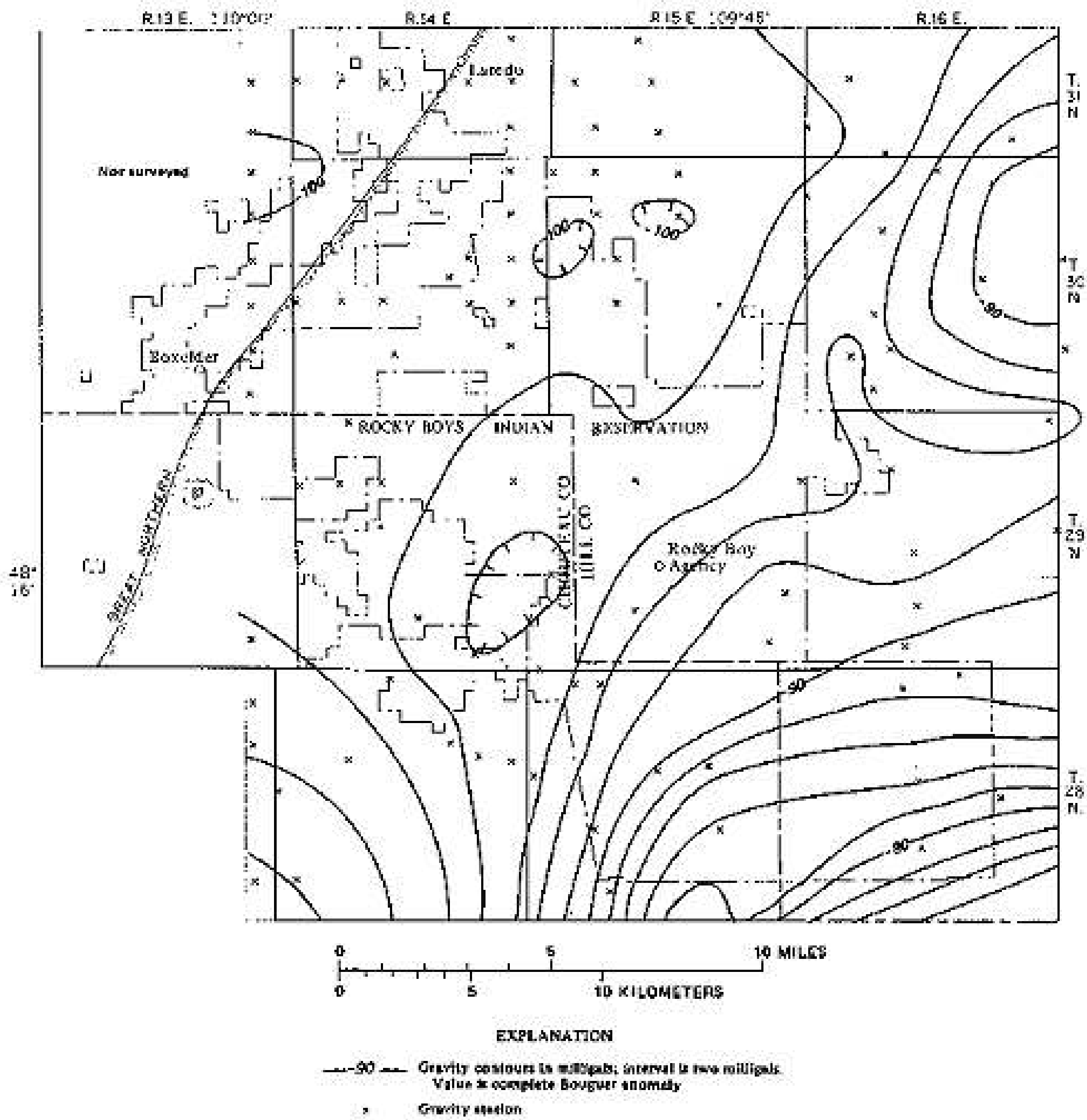

Figure 5. Complete Bouguer gravity anomaly map of the Rocky Boy's Indian Reservation and vicinity (from Peterson and Rambo, 1967).

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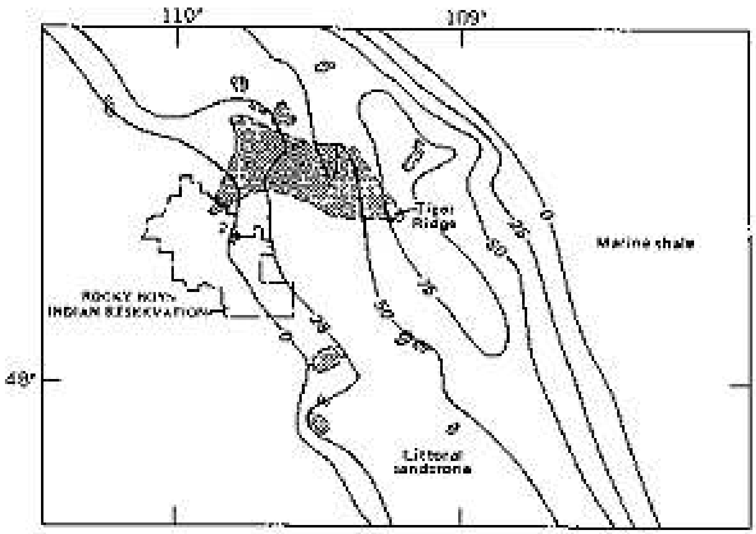
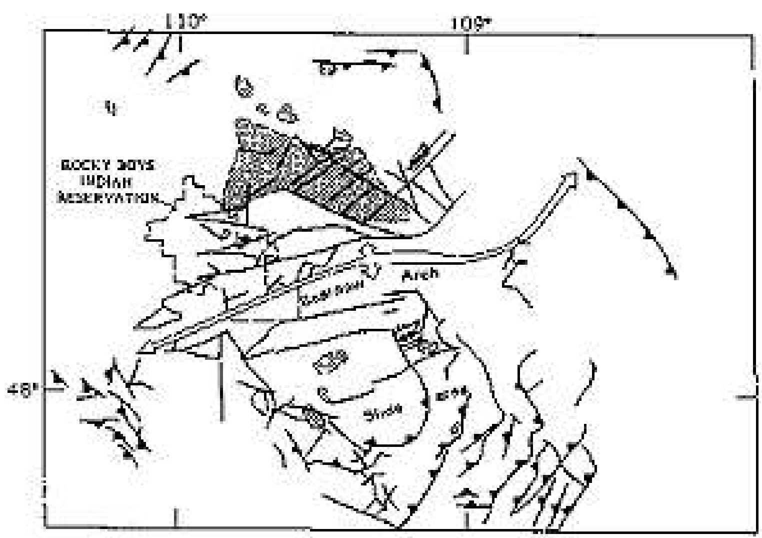


A. Isopach map of porous sandstone in upper unit of Eagle Sandstone. Isopachous interval, 25 feet.



B. Tectonic map showing thrust faults (sawteeth on upper plates) and high-angle faults.

Figure 6. Maps showing stratigraphic and structural controls of gas fields (shaded) in the Bearpaw Mountains region (from Maher, 1969). A.) Gas fields in relation to the distribution and thickness of porous sandstone in the upper part of the Eagle Sandstone; B.) Gas fields in relation to the tectonic features associated with the Bearpaw arch.

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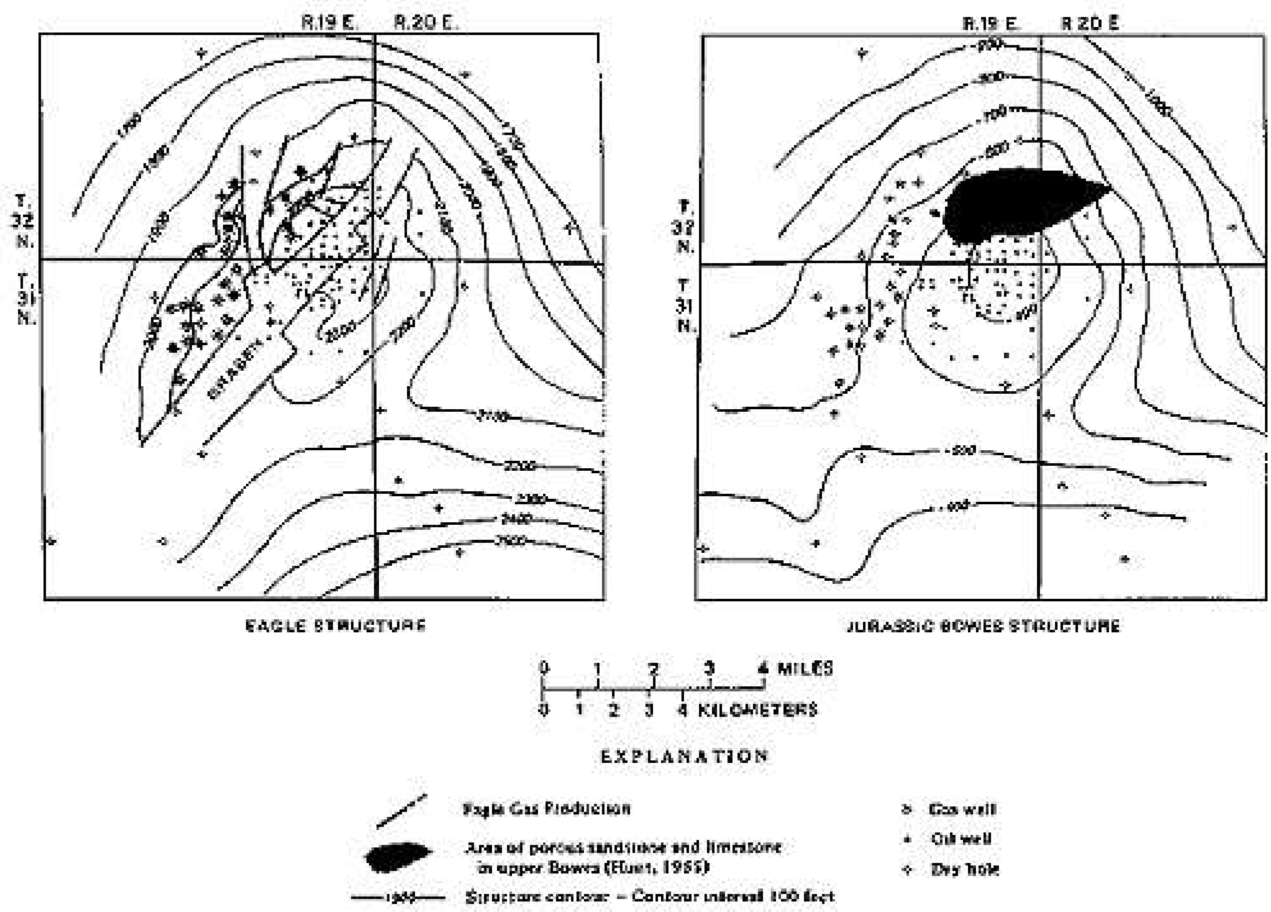

Figure 7. Maps showing structural control of gas and oil in the Bowes field, Montana (modified from Sampsel, 1969).

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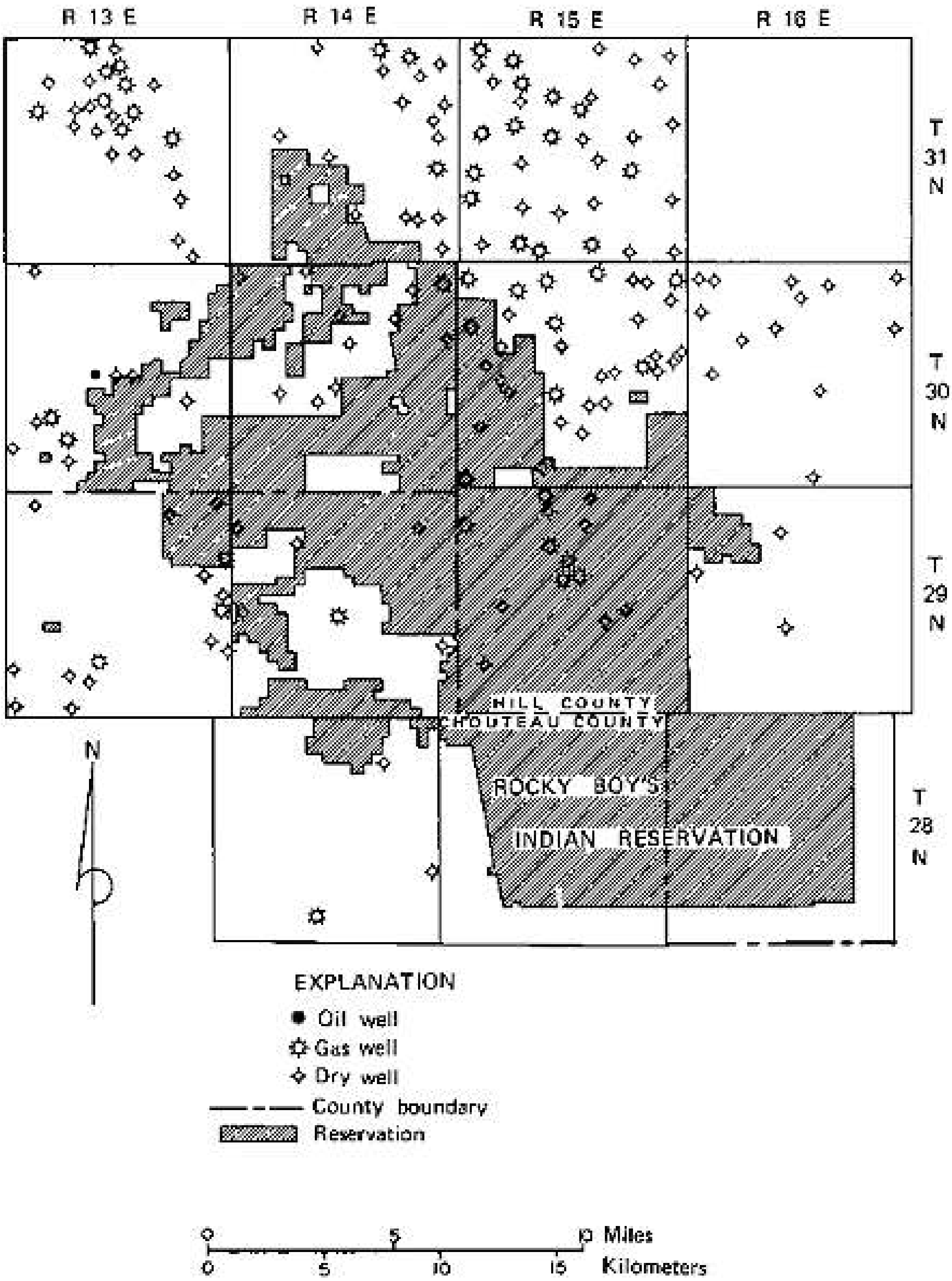

Figure 8. Map showing location of oil and gas wells on and near Rocky Boy's Indian Reservation, Montana (modified from Hubbard and others, 1963, with data from Department of Natural Resources and Conservation of the State of Montana, Oil and Gas Conservation Division; Phillips Petroleum Co.; Bureau of Indian Affairs).

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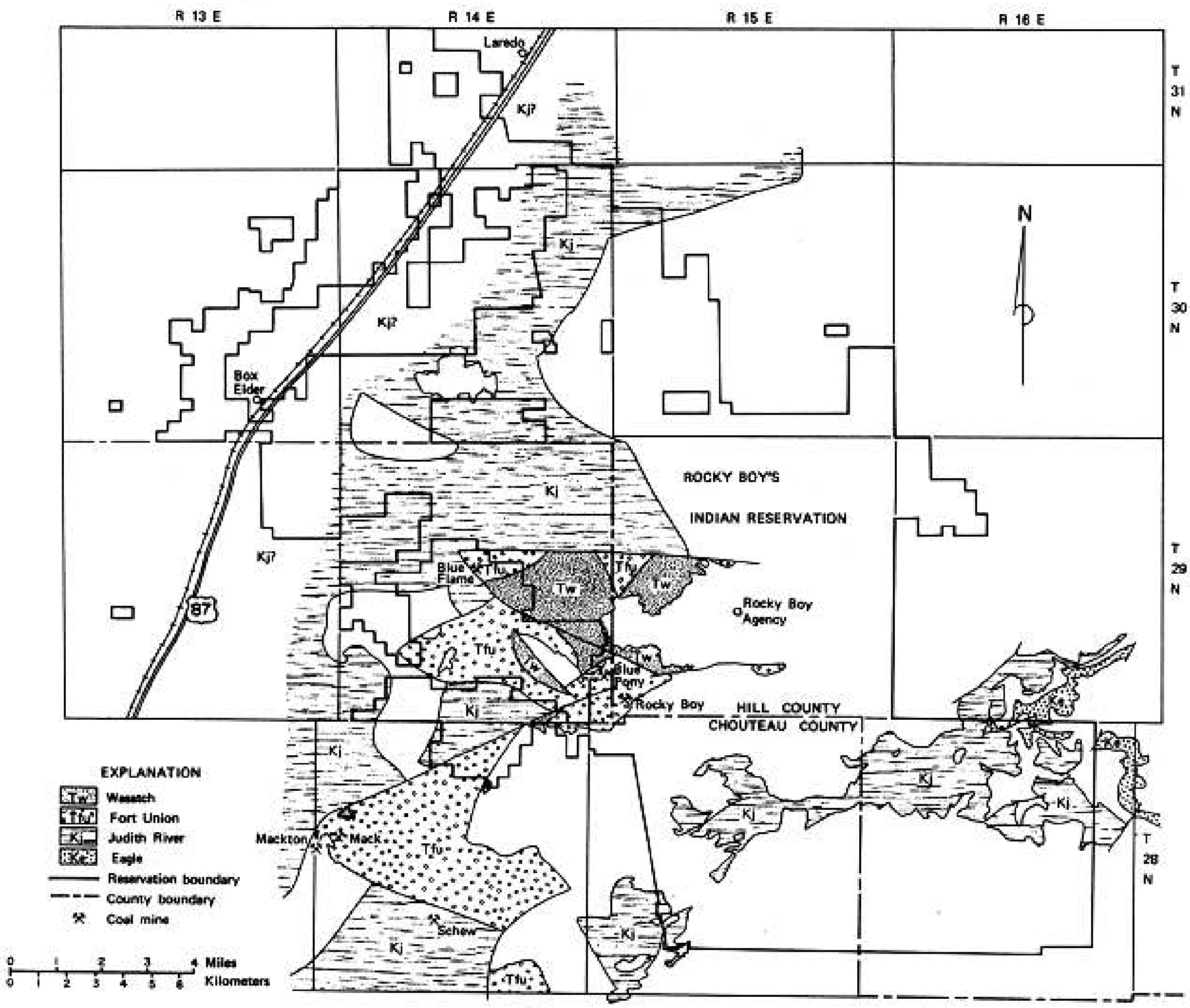

Figure 9. Map showing outcrop areas of coal-bearing Fort Union, Judith River, and Eagle Formations and locations of mines, Rocky Boy's Indian Reservation and vicinity. The Fort Union Formation underlies the noncoal-bearing Wasatch Formation (adapted from Pecora and others, 1957a, 1957b; Stewart and others, 1957).

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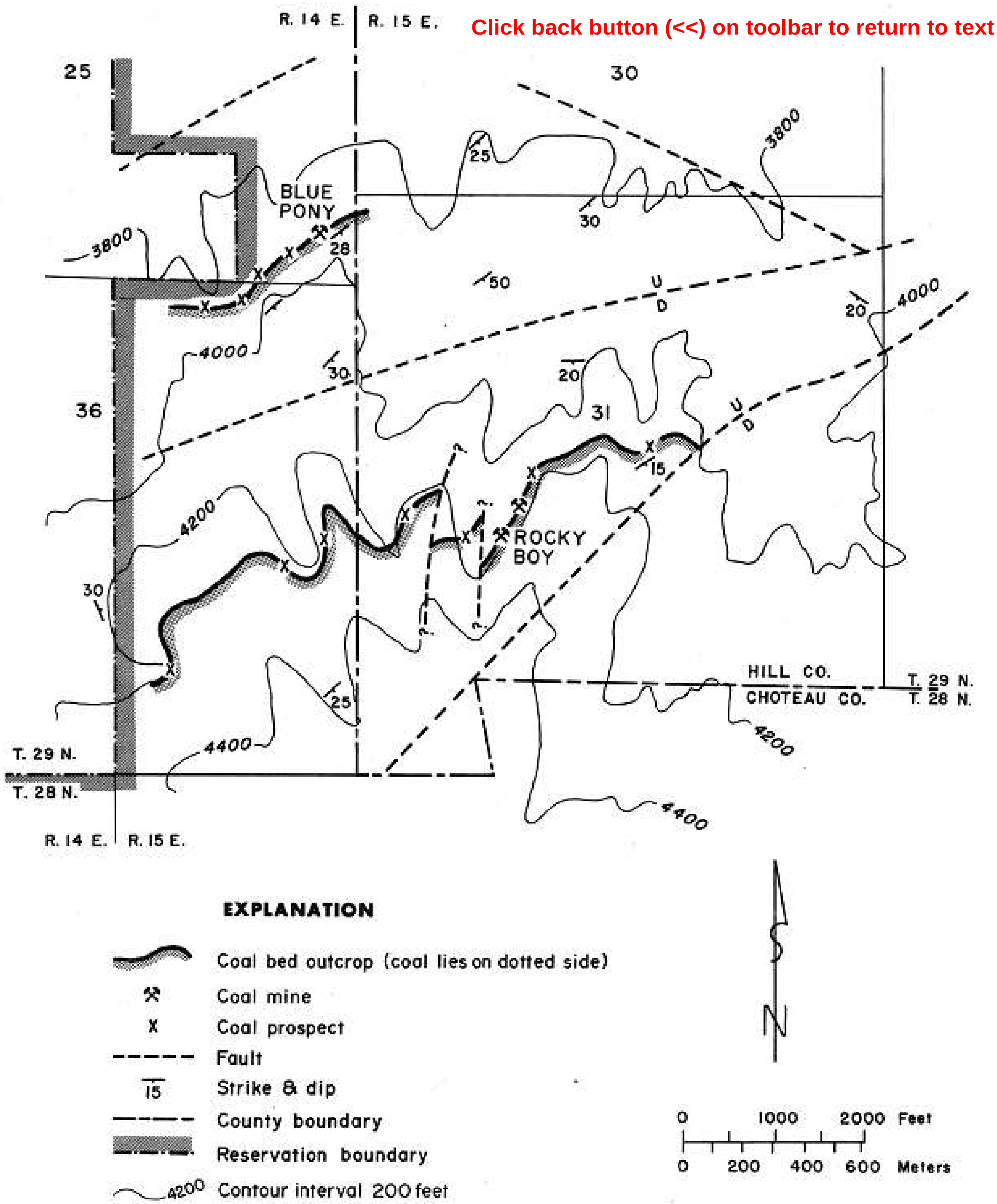

Figure 10. Map showing outcrops in the vicinity of the Rocky Boy and Blue Pony mines, Rocky Boy's Indian Reservation (adapted from Hubbard, Roby, and Henkes, 1963).

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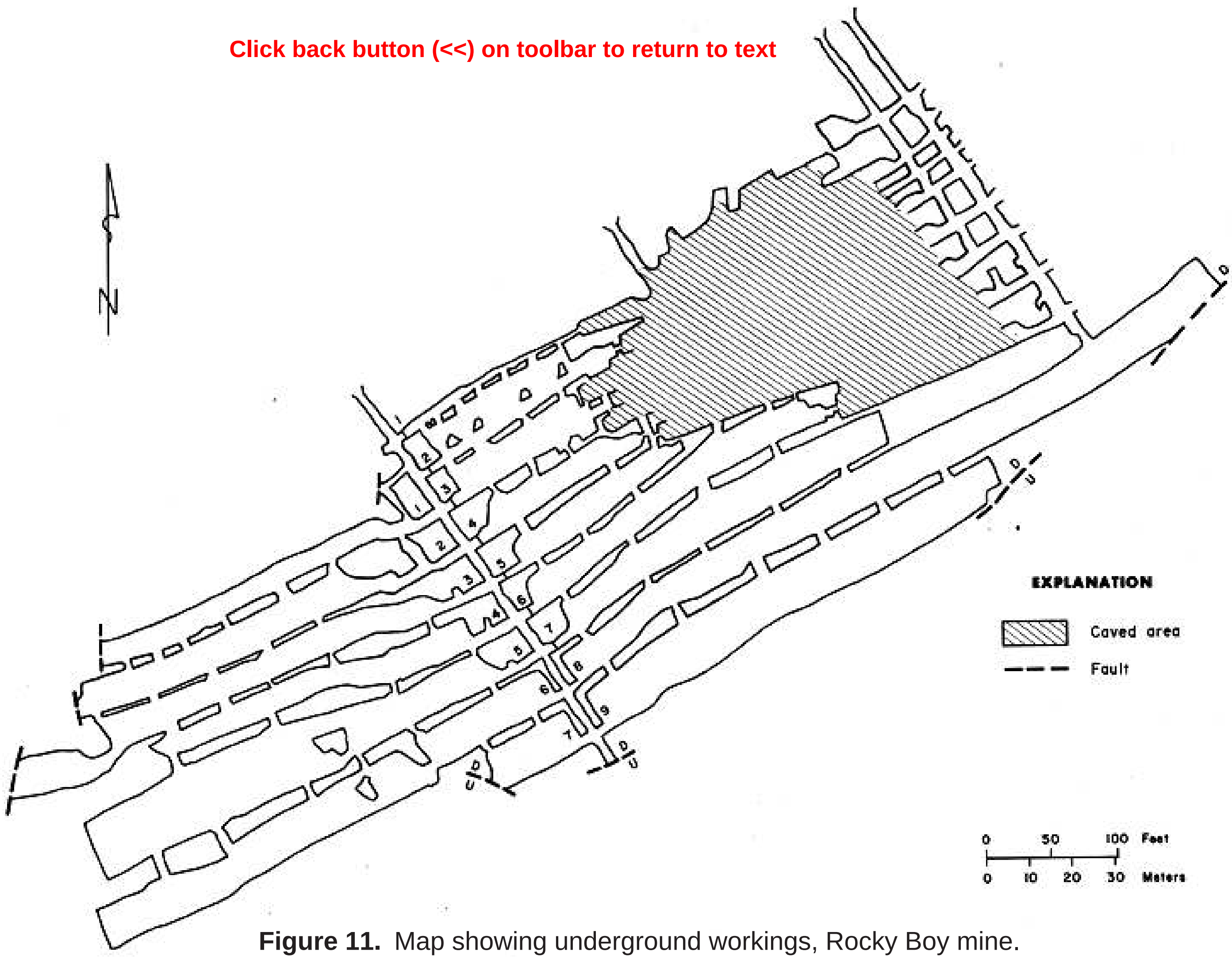

Figure 11. Map showing underground workings, Rocky Boy mine.

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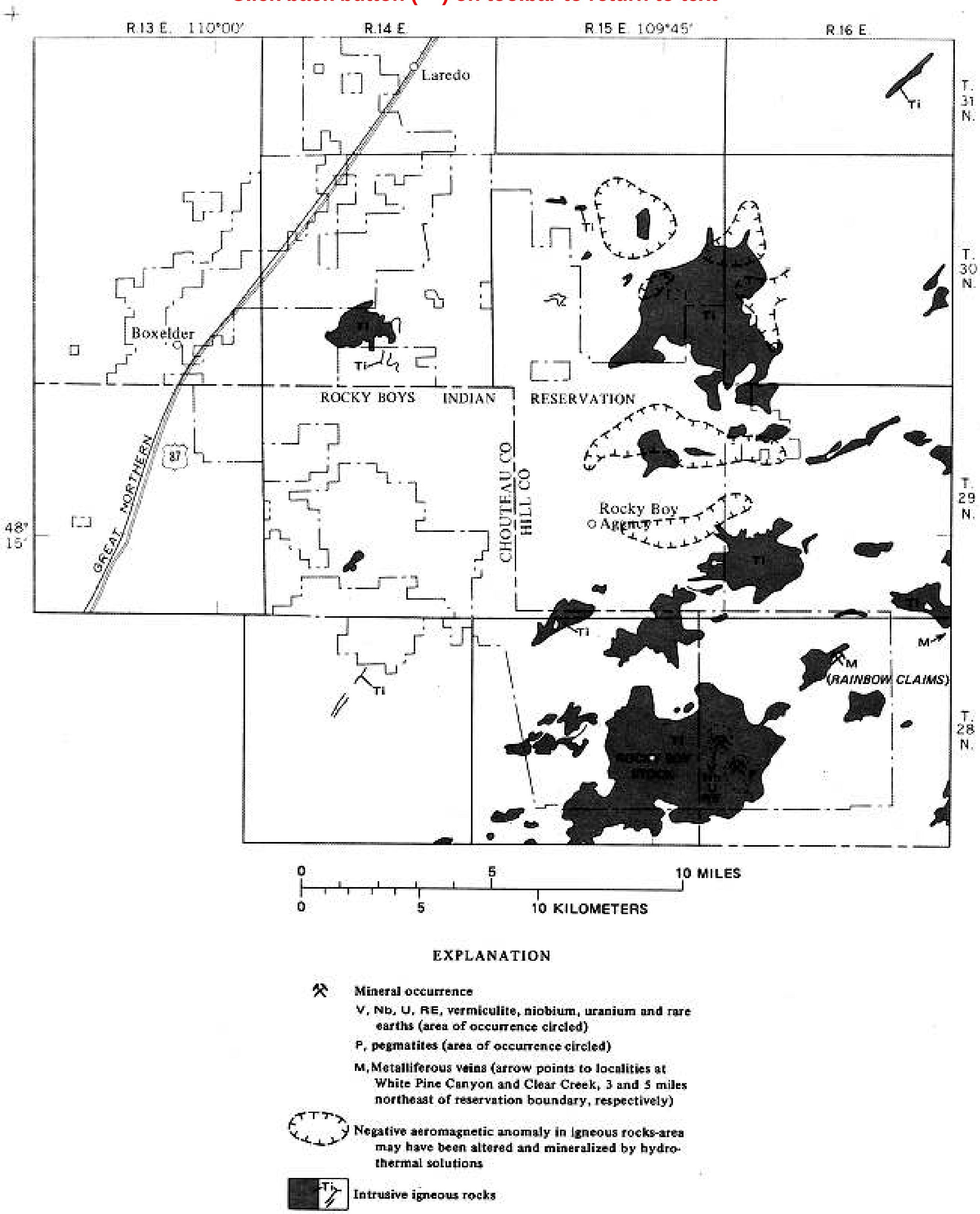

Figure 12. Map showing occurrences of metallic and other mineral resources in igneous rocks of the Rocky Boy's Reservation and vicinity. Also shown are areas of alteration and possible mineralization.

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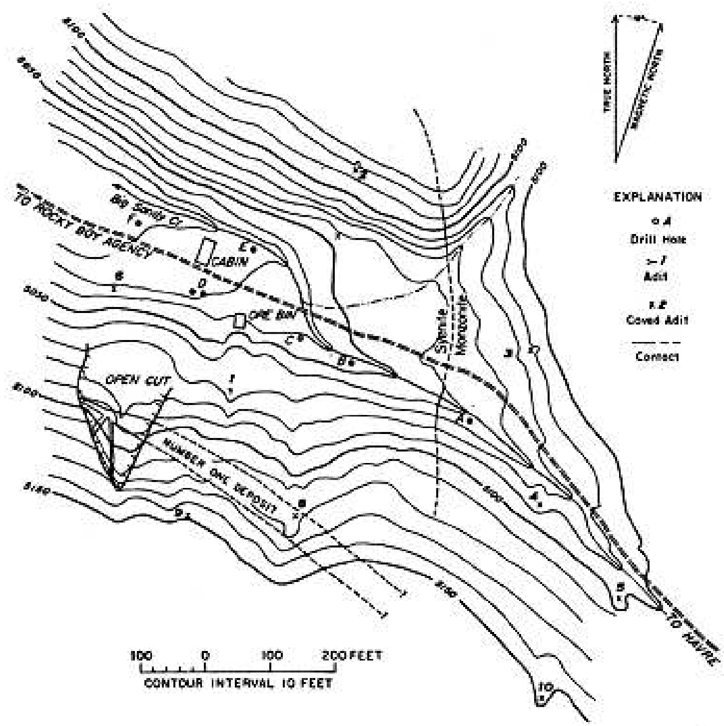

Figure 13. Map showing location of Number One carbonatite deposit (uranium, niobium, and rare earth minerals), vermiculite prospects, and diamond-drill holes, Big Sandy Creek, Montana (from Pecora, 1962).

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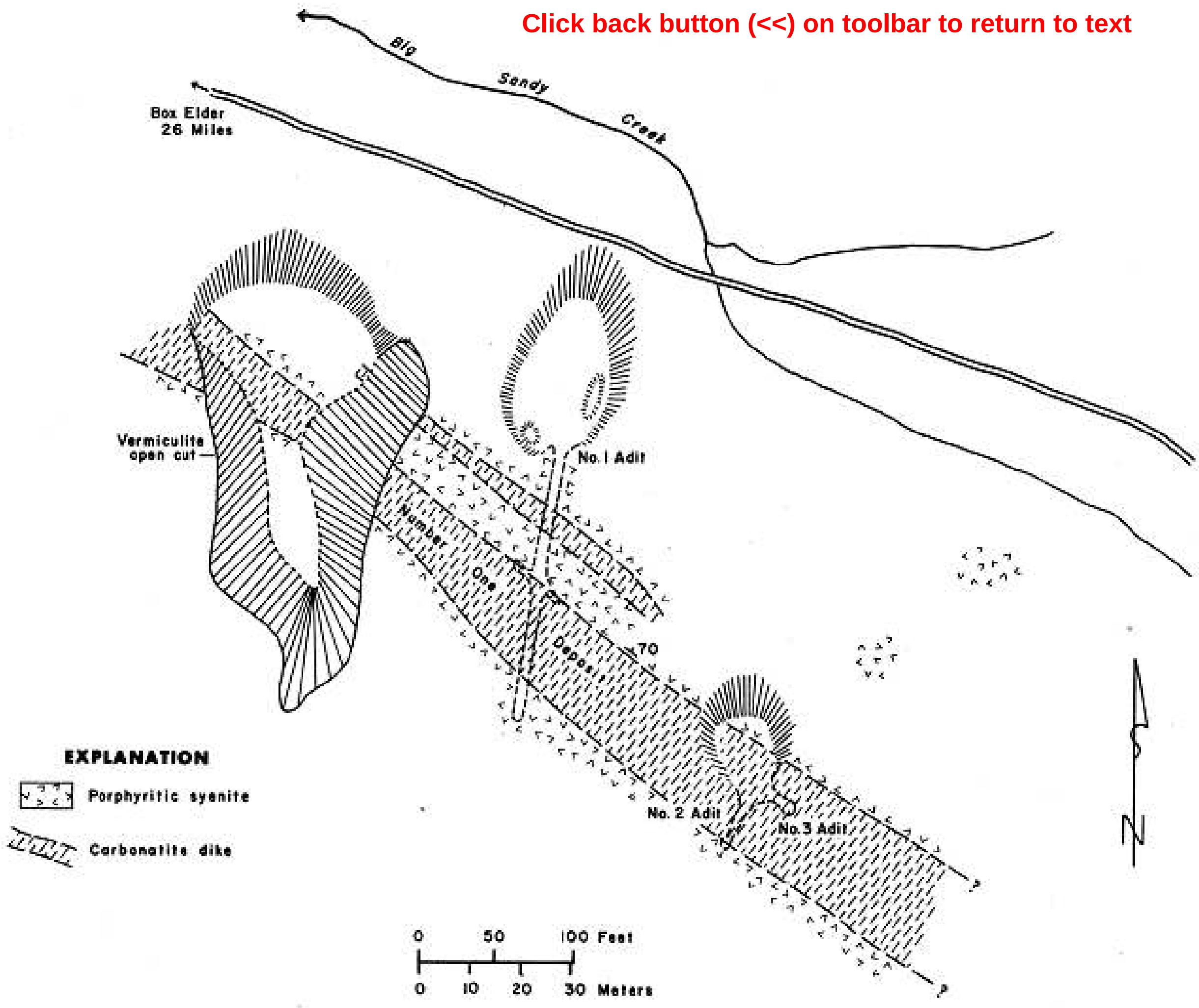

Figure 14. Map showing vermiculite mine and vicinity, Rocky Boy's Indian Reservation (adapted from Hubbard, Roby, and Henkes, 1963; Pecora, 1962).

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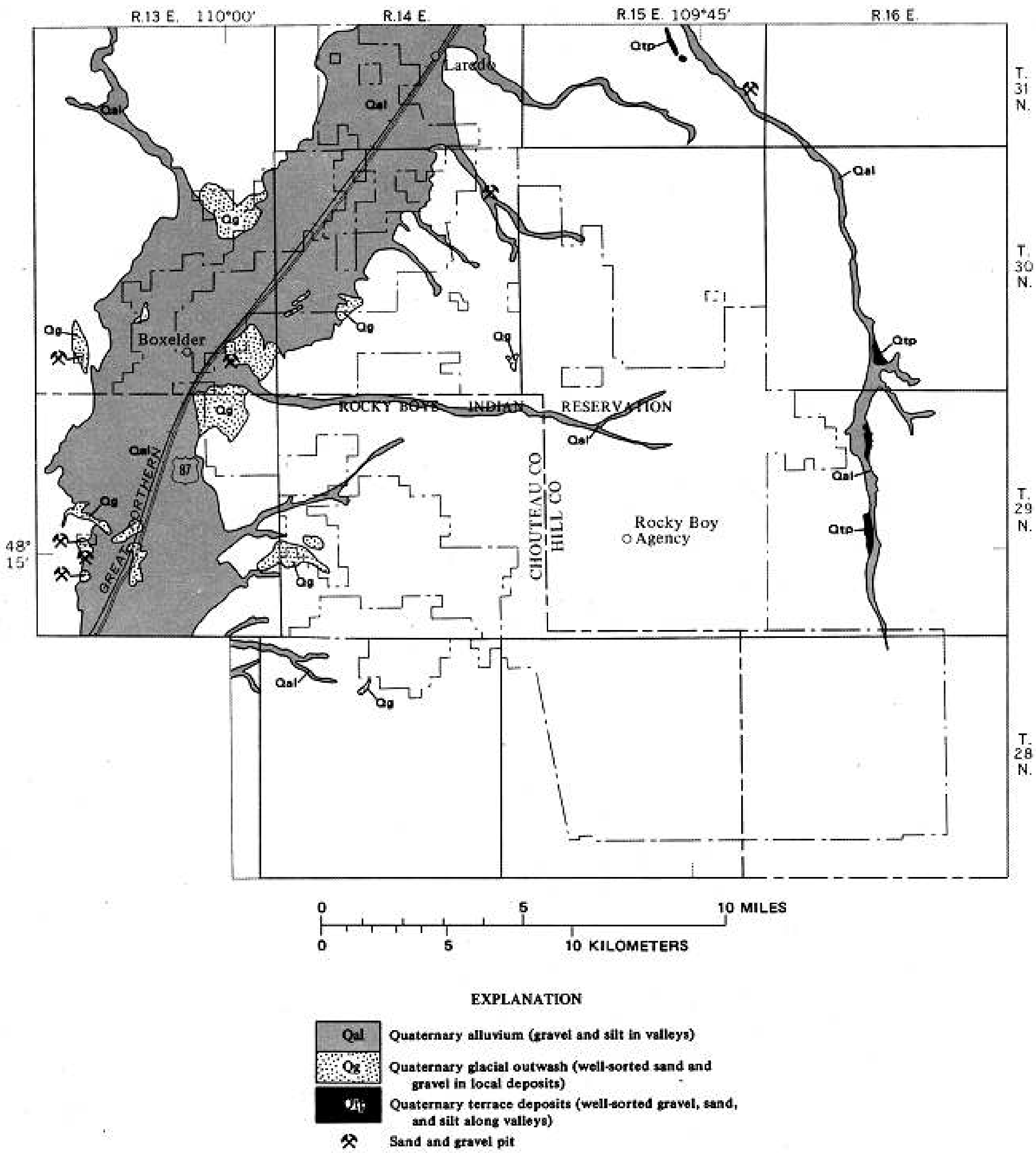

Figure 15. Map showing sand and gravel resources on the Rocky Boy's Indian Reservation and vicinity.

Quarry for riprap
(Bullhook Creek)

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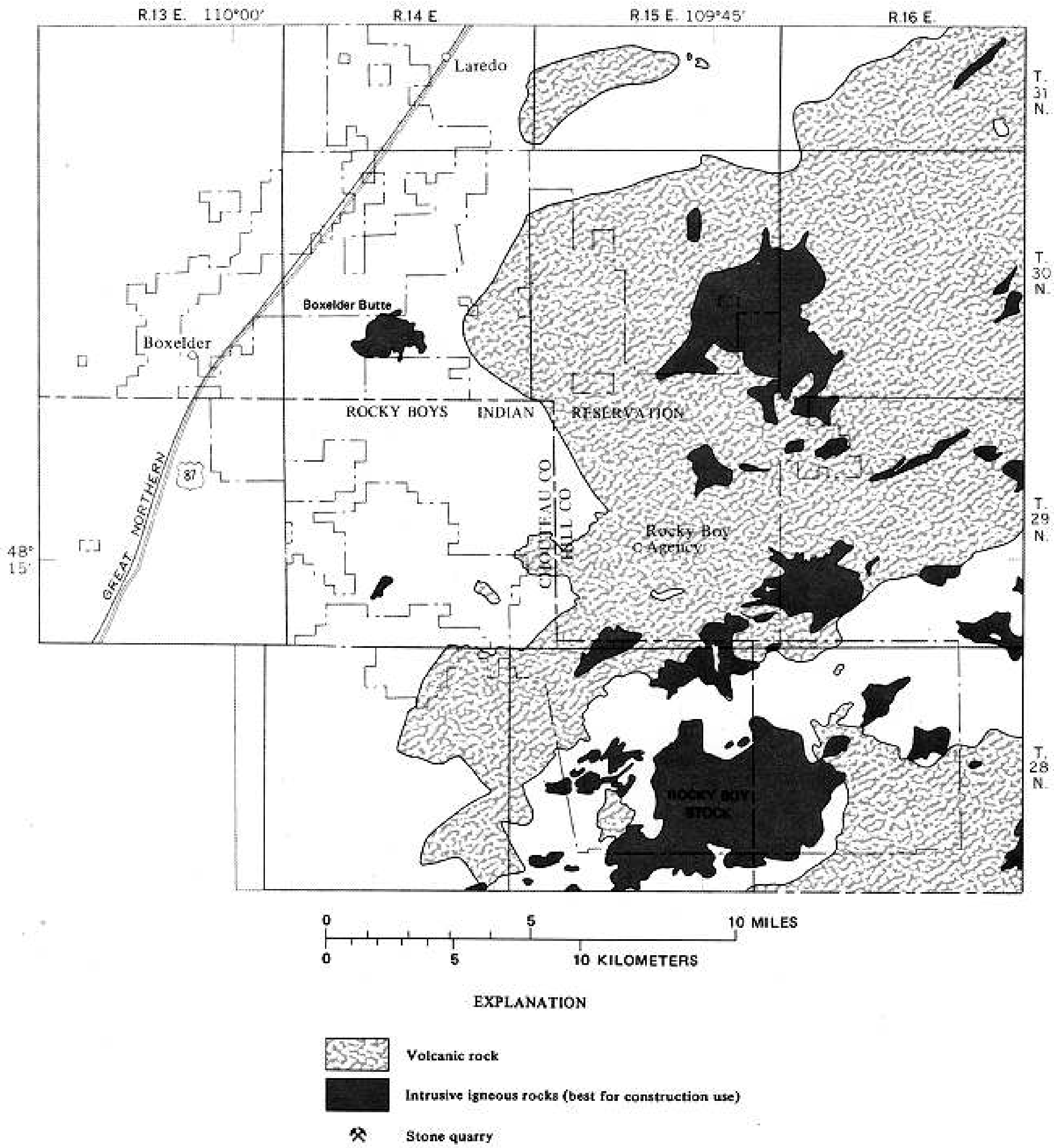

Figure 16. Map showing location of stone resources on the Rocky Boy's Indian Reservation and vicinity.